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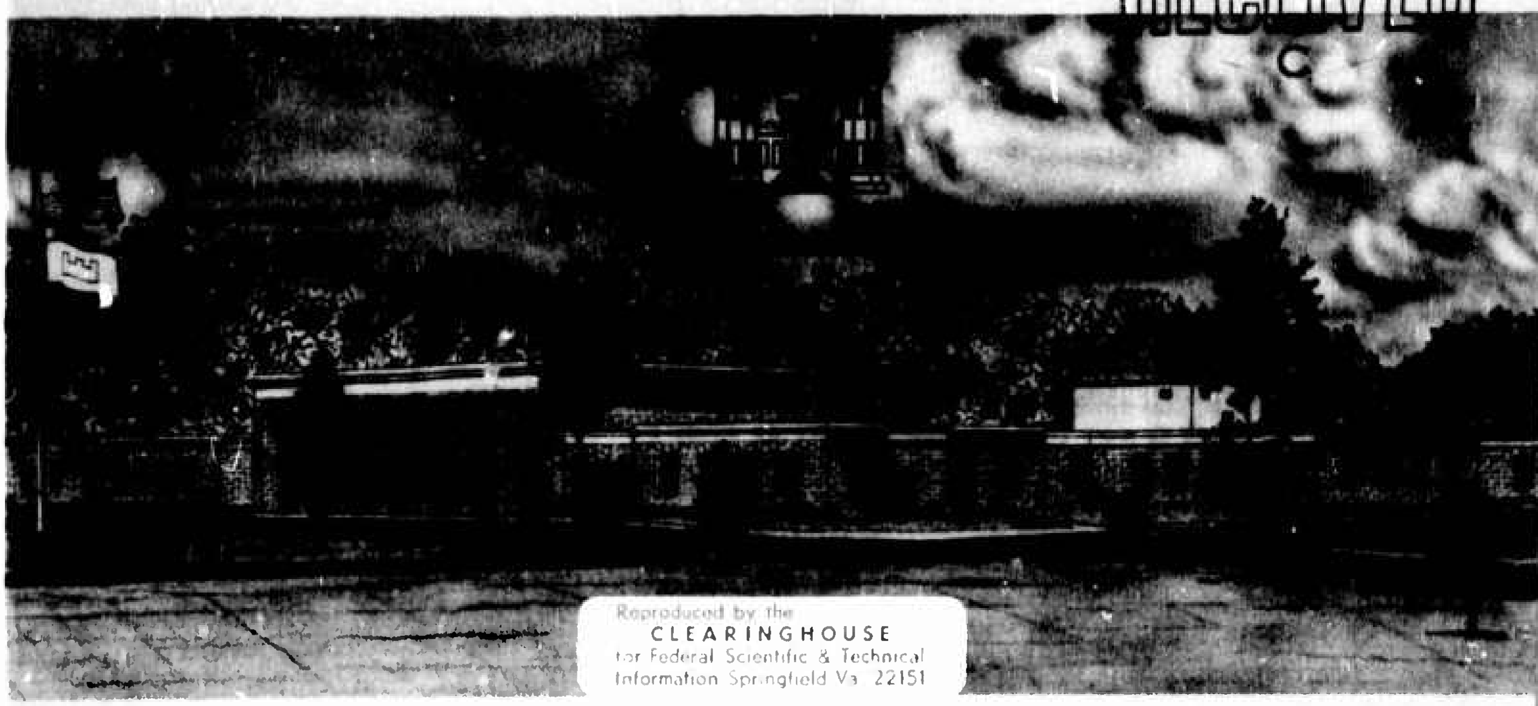
AIRBLAST LOADING OF A LARGE METAL SHIPPING CONTAINER

Laboratory Investigation

by

G. L. Carre, R. E. Walker



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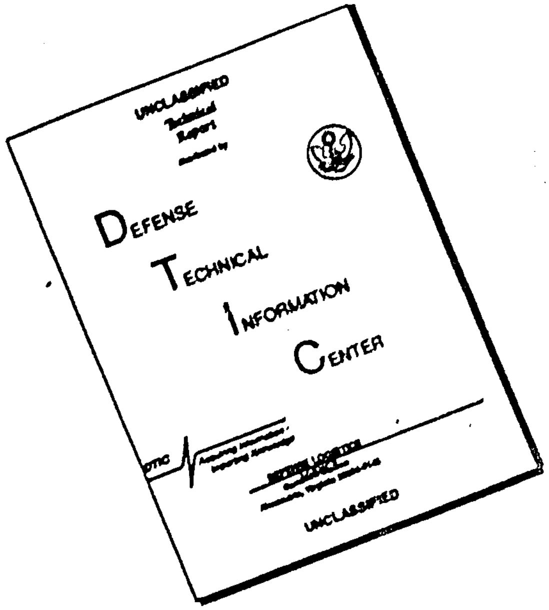

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Task 01

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ARMY-MRC VICKSBURG, MISS.

ABSTRACT

The objective of the test program reported herein was to determine if a large metal shipping container would provide a sufficient degree of protection from simulated nuclear weapon blast effects to make it suitable as a small protective shelter.

This report describes the tests of two Container Express (CONEX) containers that were instrumented and subjected to blast loads in the Large Blast Load Generator (LBLG) facility at the U. S. Army Engineer Waterways Experiment Station (WES).

The containers were buried in dense, dry sand with 18 inches of sand over the roof and subjected to blast load pressures of approximately 11, 15, and 34 psi. A total of 45 channels of instrumentation were used to measure the following parameters: strain in the roof, sidewall, and floor; vertical deflection of the roof; accelerations in the roof, sidewall, floor, and free field; blast pressure at the soil surface and free field; and pressure inside the container.

For the first two tests, a container was placed base down in the LBLG and subjected to pressures of 11 and 34 psi, respectively. The initial test caused only moderate damage to the container; however, complete roof collapse resulted from the second test. For the final test, an inverted (base up) container was subjected to a pressure of 15 psi. Damage to the container was moderate.

Results of the test program indicate that the CONEX container could be utilized as a small protective shelter. If the container were buried with the base up, it is believed that it would withstand a pressure load of approximately 20 psi.

PREFACE

The investigation reported herein was accomplished by personnel of the Nuclear Weapons Effects Division (NWED), U. S. Army Engineer Waterways Experiment Station (WES), during the period July through September 1967. The work was sponsored by the Office, Chief of Engineers, Department of the Army, as a part of Task 01, "Engineering Studies and Investigations" in the "Military Engineering Applications of Nuclear Weapons Effects Research" (MEANWER) project.

The study was under the general supervision of Mr. G. L. Arbuthnot, Jr., Chief of NWED, and under the direct supervision of Mr. W. J. Flathau, Chief, and Mr. J. V. Dawsey, Jr., Project Manager, of the Protective Structures Branch. This report was prepared by Messrs. G. L. Carre and R. E. Walker of the Protective Structures Branch.

Directors of the WES during the conduct of this study and the preparation of this report were COL John R. Oswalt, Jr., CE, COL Levi A. Brown, CE, and COL Ernest D. Peixotto, CE. Technical Directors were Mr. J. B. Tiffany and Mr. F. R. Brown.

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CONVERSION FACTORS, BRITISH TO METRIC UNITS OF MEASUREMENT

British units of measurement used in this report can be converted to metric units as follows.

Multiply	By	To Obtain
inches	2.54	centimeters
feet	0.3048	meters
cubic feet	0.0283168	cubic meters
pounds	0.45359237	kilograms
tons (2,000 pounds)	907.185	kilograms
pounds per square inch	0.070307	kilograms per square centimeter
kips per square inch	70.307	kilograms per square centimeter
pounds per cubic foot	16.0185	kilograms per cubic meter
inches per second	2.54	centimeters per second
feet per second	0.3048	meters per second

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND

The Container Express (CONEX) is a large metal shipping container that can hold materials weighing up to 5 tons.[1] The CONEX was designed to speed the movement of cargo and to protect goods from loss, damage, and pilferage. Thousands of the containers have been shipped to Southeast Asia (SEA). As very few containers have been returned, it is evident that countless additional uses have been found for the CONEX in the Theater of Operations. For example, the metal containers are being converted into dispensaries, offices, supply rooms, command posts, and fighting fortifications.

Since the CONEX is being successfully used to withstand the effects of conventional weapons, it was hypothesized that a standard container might be adequate to resist the airblast loads from nuclear weapon detonations.

1.2 OBJECTIVE

The objective of this study was to determine the response of a buried CONEX subjected to simulated nuclear weapon blast effects. The specific objective was to determine if the CONEX, as manufactured, would provide a sufficient degree of protection to make it suitable as a small protective shelter when subjected to airblast loading conditions characteristic of nuclear weapon detonations.

1.3 SCOPE

To accomplish the objective of this study, three tests were conducted in the Large Blast Load Generator (LBLG) facility at the U. S. Army Engineer Waterways Experiment Station (WES) on CONEX containers buried in sand to a depth of 18 inches. The first CONEX was placed in the LBLG base down and subjected to surface pressures of 11 and 34 psi. A second CONEX was then placed in the LBLG base up and subjected to a pressure of 15 psi. The structures for all tests were instrumented to record the following measurements: (1) steel

[1] A table of factors for converting British units of measurement to metric units is presented on page 7.

strains, (2) top, base, and sidewall acceleration, and (3) internal pressures. Additionally, free-field acceleration, and soil stress and surface pressure measurements were recorded.

CHAPTER 2

EXPERIMENTAL PROGRAM

2.1 TEST APPARATUS

The LBLG test device was designed primarily to test large model or prototype protective structures subjected to pressures simulating those generated by both kiloton and megaton nuclear devices. The structures can be subjected to dynamic loads to 500 psi at a rise time of approximately 2 to 4 msec and at durations ranging from milliseconds to several seconds.

The LBLG (Figure 2.1) has two basic components, the central firing station (CFS) and the test chamber. The CFS is a massive, posttensioned, prestressed concrete reaction structure designed to resist the dynamic loads generated in the test chamber. The two test chambers are cylindrical steel bins approximately 23 feet in diameter that contain the test media and test structures. The test chamber (Figure 2.2) is composed of three 3-1/3-foot-high C rings that are stacked on a wheel-mounted platen. One B ring containing a baffle grid and 15 firing tubes is seated on the uppermost C ring. To complete the test chamber, one A ring equipped with quick-opening, blast-exhaust valves is seated on the B ring.

The assembled test chamber is rolled into the tunnel of the CFS, the platen is lowered to rest on the base slab, and the A ring is elevated to bear against the ceiling of the CFS. The test device is described in detail in References 1 and 2.

2.2 CONEX DESCRIPTION

The CONEX (Figure 2.3) is a large, metal, box-shaped, reusable shipping container. Two sizes, 135 and 295 ft^3, are available, however, only the larger size was considered for this test program. The load-carrying capacity of the large container is 10,000 pounds. Its tare weight is approximately 1,600 pounds. Access to the container is provided by two doors that close to form the container front and are secured with a quick-opening door handle.

The container has internal dimensions of 8 feet 2 inches long, 6 feet wide, and 6 feet high. Outside dimensions are 8 feet 6 inches long, 6 feet 3 inches wide, and 6 feet 10-1/2 inches high. Inside and outside volumes of the container are 295 and 365 ft^3, respectively.

The large container is fabricated from 18-gage-thick corrugated steel welded at all joints. A double wall thickness is provided at the container roof and floor. This double thickness is obtained by spot-welding an 18-gage-thick plate to the top surface of the corrugated roof and floor.

The container is mounted on 3/16-inch-thick steel skids, and forged-steel lifting lugs are provided to facilitate handling and storage. A 1/4-inch-thick steel bar, 6 inches wide by 8 feet 2 inches long, is welded to the outside floor surface. This bar is centered between the skids and serves as a floor stiffener.

2.3 INSTRUMENTATION

The test structure and free-field gage locations remained the same for all three tests and are shown in Figures 2.4 through 2.6. Some of the transducers used are shown in Figure 2.7.

2.3.1 Pressure Measurements. Strain-gage-type pressure transducers were used to determine free-field pressure, surface pressure, and pressure inside the structure. Eight gages were positioned at the ground surface and two inside the structure. The sand surface gages were mounted on wooden trusses buried flush within the sand (Figure 2.8).

2.3.2 Acceleration Measurements. Structure and free-field accelerations were measured at locations shown in Figures 2.4 through 2.6 with strain-gage-type accelerometers. Free-field accelerometers were cast in sand-plaster mixtures with densities approximating those of the sand.

2.3.3 Strain Measurements. Strains in the roof, floor, and one side of the CONEX were measured at locations shown in Figure 2.5 using foil-type strain gages (gage length, 1/4 inch; gage resistance, 120 ohms; gage factor, 2.04). Twenty strains were measured by 10 gages positioned on the inside and 10 on the outside container surfaces. At roof, floor, and sidewall inside and outside center spans, two single-element gages were placed at 90-degree angles to each other to indicate two-directional steel strain. To obtain a four-arm bridge circuit, the single active gages at each gage location on the structure were matched with three similar gages mounted on steel blocks located outside the test chamber.

2.3.4 Deflection Measurements. Deflection of the CONEX roof was measured with a linear potentiometer. A steel pipe was mounted to the container floor to support the gage. The deflection gage was used only in the first test and had a capability of measuring deflections of 3-1/2 inches up or down. Figure 2.6 shows the deflection gage mounted on the structure.

2.3.5 Soil Stress Measurements. Free-field soil stress measurements were made for all tests. Soil stress was measured using diaphragm-pressure gages developed at WES (Reference 3). The soil pressure gages were placed at the structure roof, middle, and floor elevations.

2.3.6 Data Recording Equipment. Data were recorded during the test with four high-speed oscillographs operating at a chart speed of 160 in/sec for 5-second durations and four magnetic-tape recorders operating at recording speeds of 60 in/sec.

2.4 TEST GEOMETRY AND PROCEDURES

For each test, the CONEX container was placed in the center of the LBLG test chamber in order that side effects would be minimized and a balanced load distribution obtained. The base of the container was approximately 2 feet from the test chamber bottom; therefore, for practical purposes, it was assumed that the base rested on a rigid foundation. After the CONEX had been placed in the LBLG, all electronic instrumentation was connected and electrically balanced.

A local sand, designated Cook's Bayou sand, used for backfilling in all tests is described in detail in Reference 2. The sand was placed in the test chamber in 6-inch increments and compacted with a plate vibrator to a density of about 102 pcf, at which the angle of internal friction was approximately 37 degrees. The sand was placed to an elevation 18 inches above the containers for all tests. An automatic control system sequentially started the data recording devices, ignited the charge, and opened the blast valves to exhaust the pressure.

For the first two tests, a CONEX was placed in the LBLG base down, as shown in Figure 2.8a. The third test geometry was identical with that illustrated for the two previous tests, but the container was inverted (Figure 2.8b).

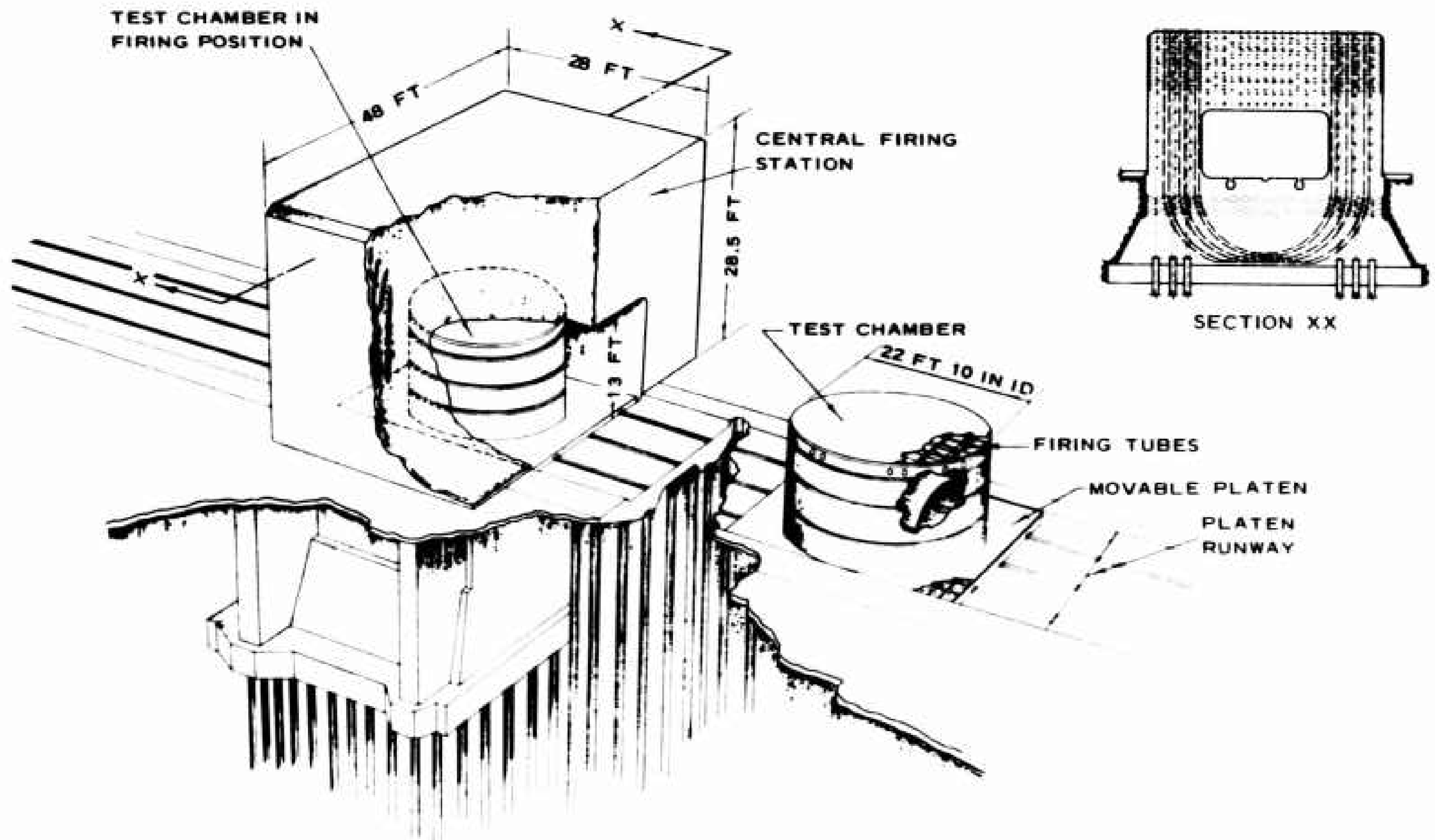


Figure 2.1 Large Blast Load Generator (LBLG).

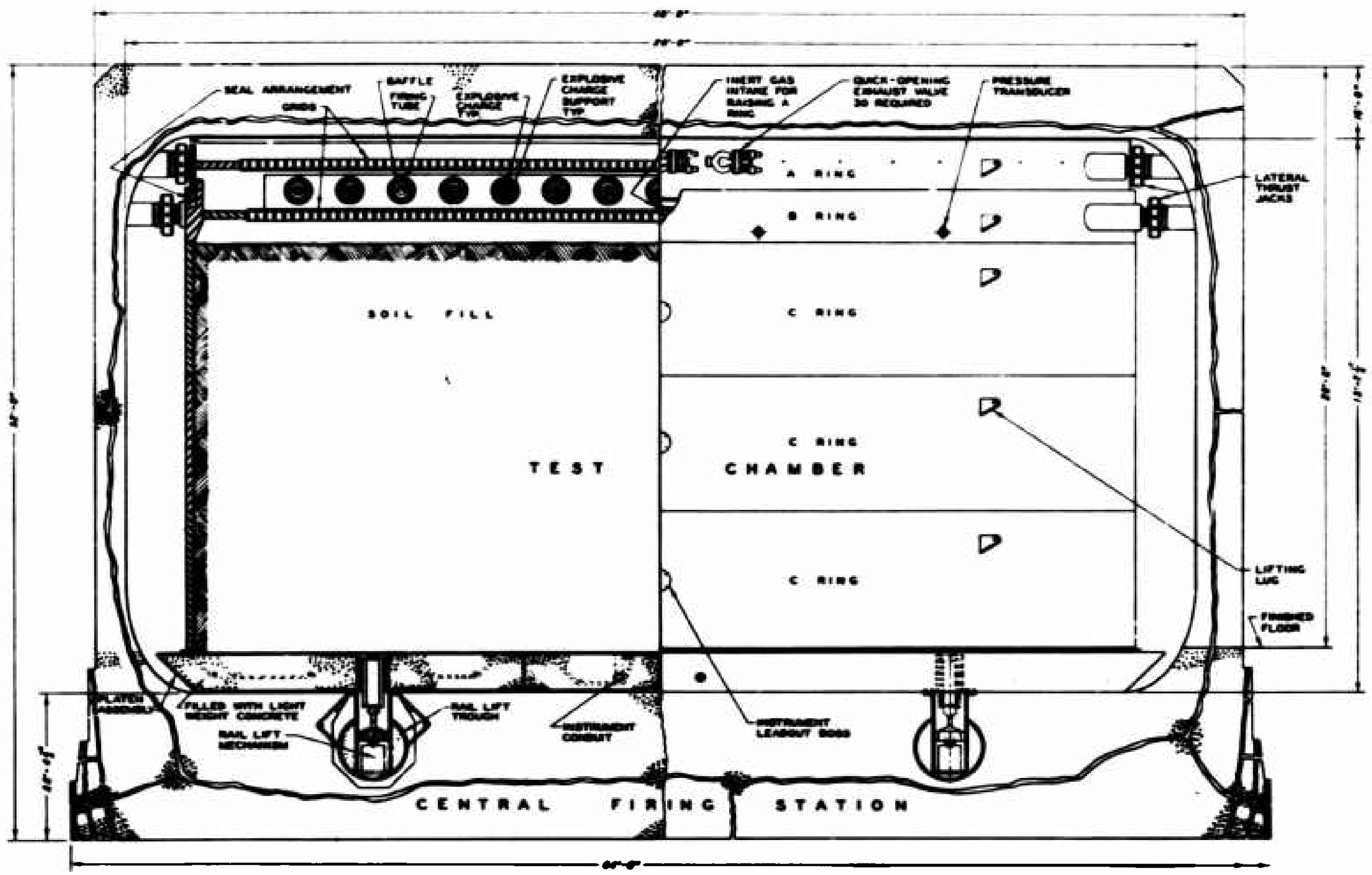


Figure 2.2 Half-section of the Blast Load Generator.

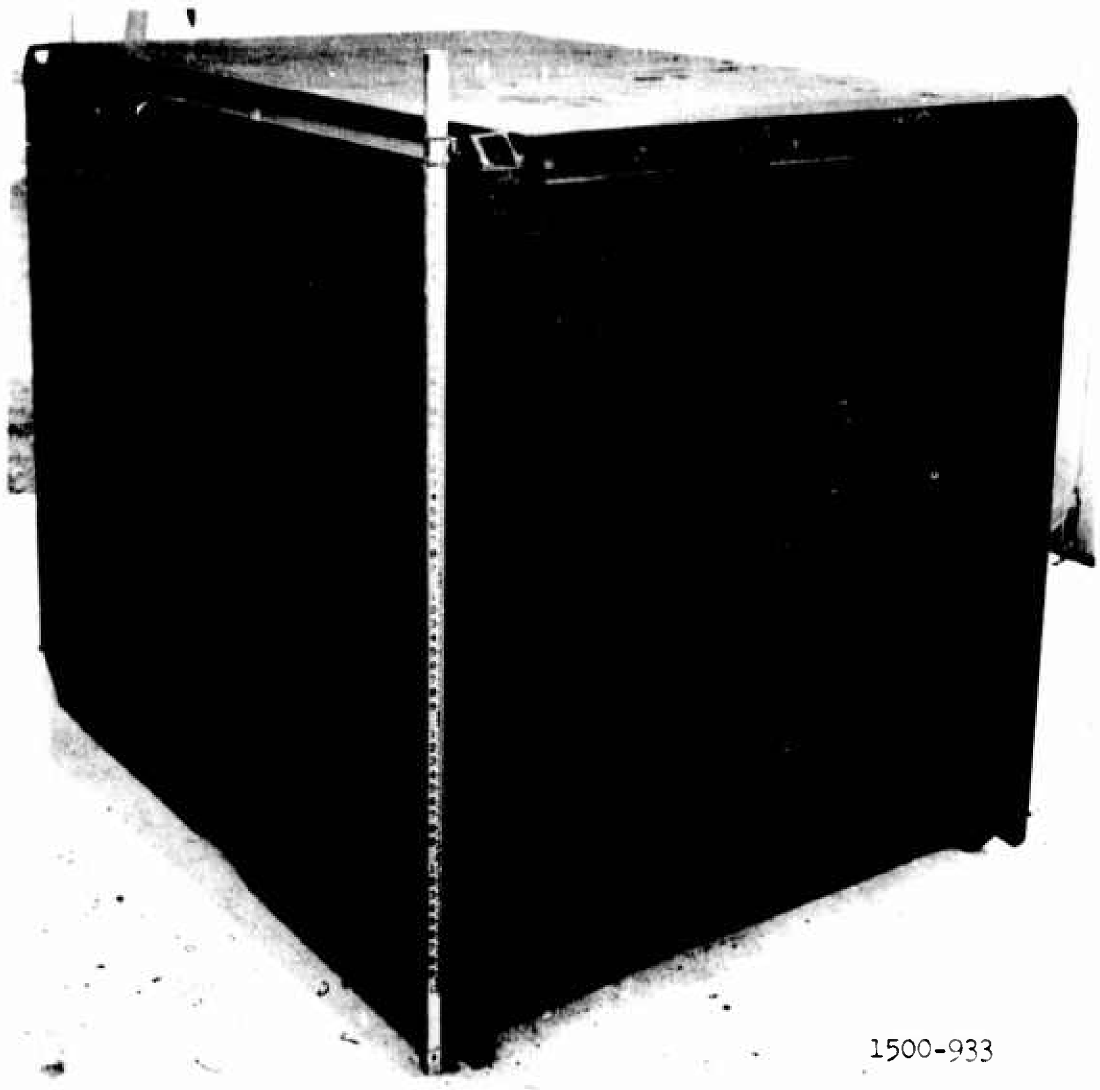


Figure 2.3 Large CONEX.

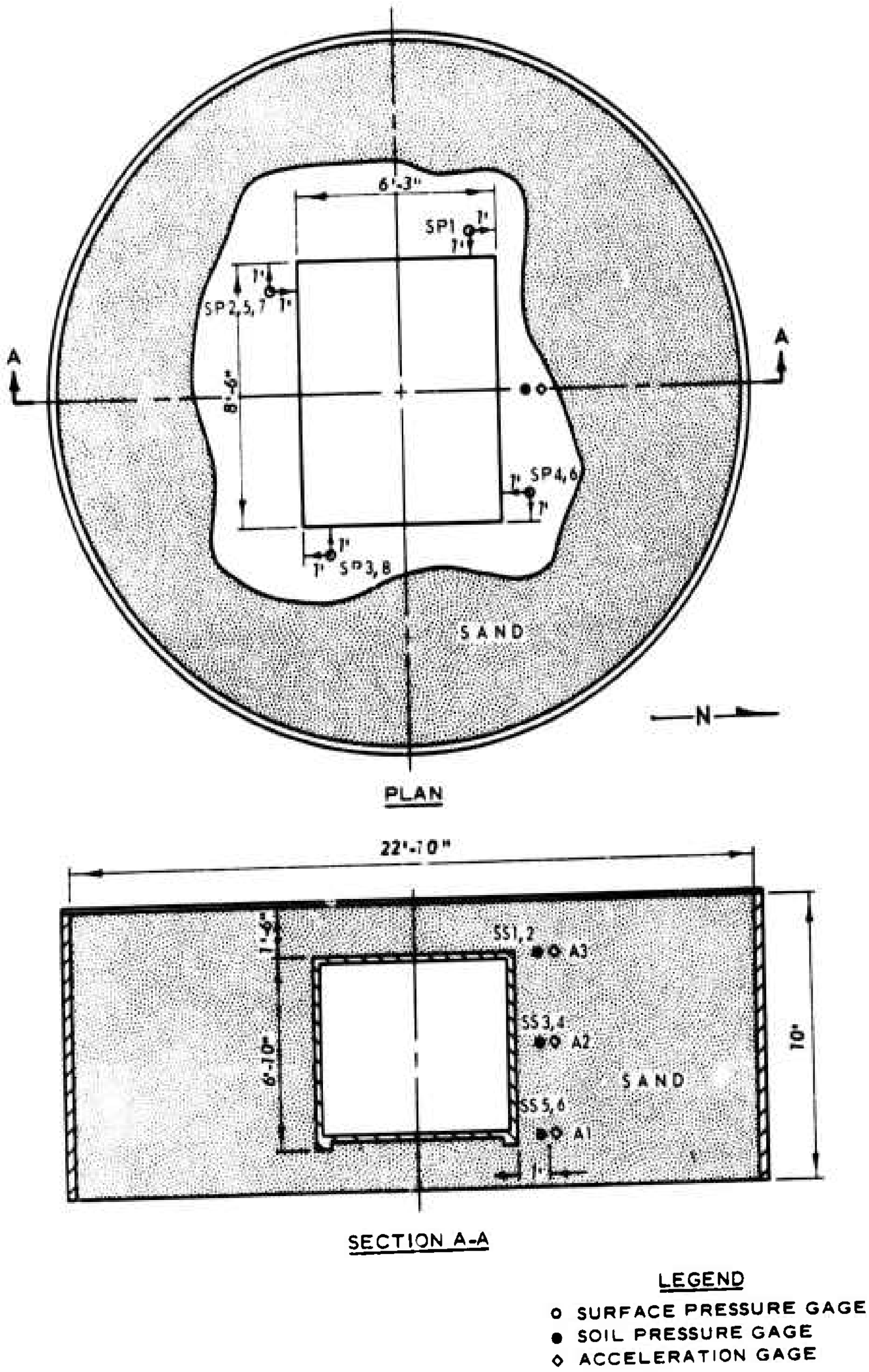


Figure 2.4 CONEX location and position of free-field instrumentation in LBLG test chamber.

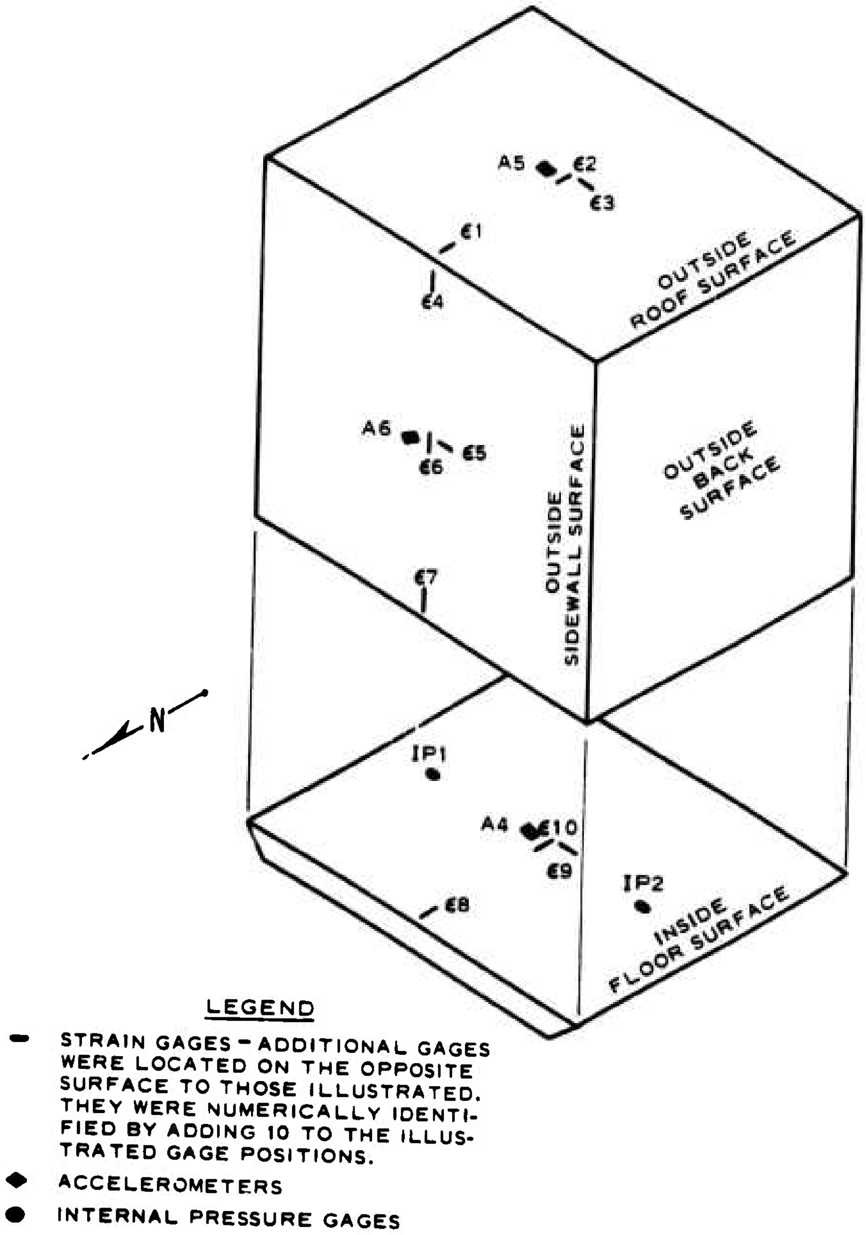


Figure 2.5 Locations of CONEX.

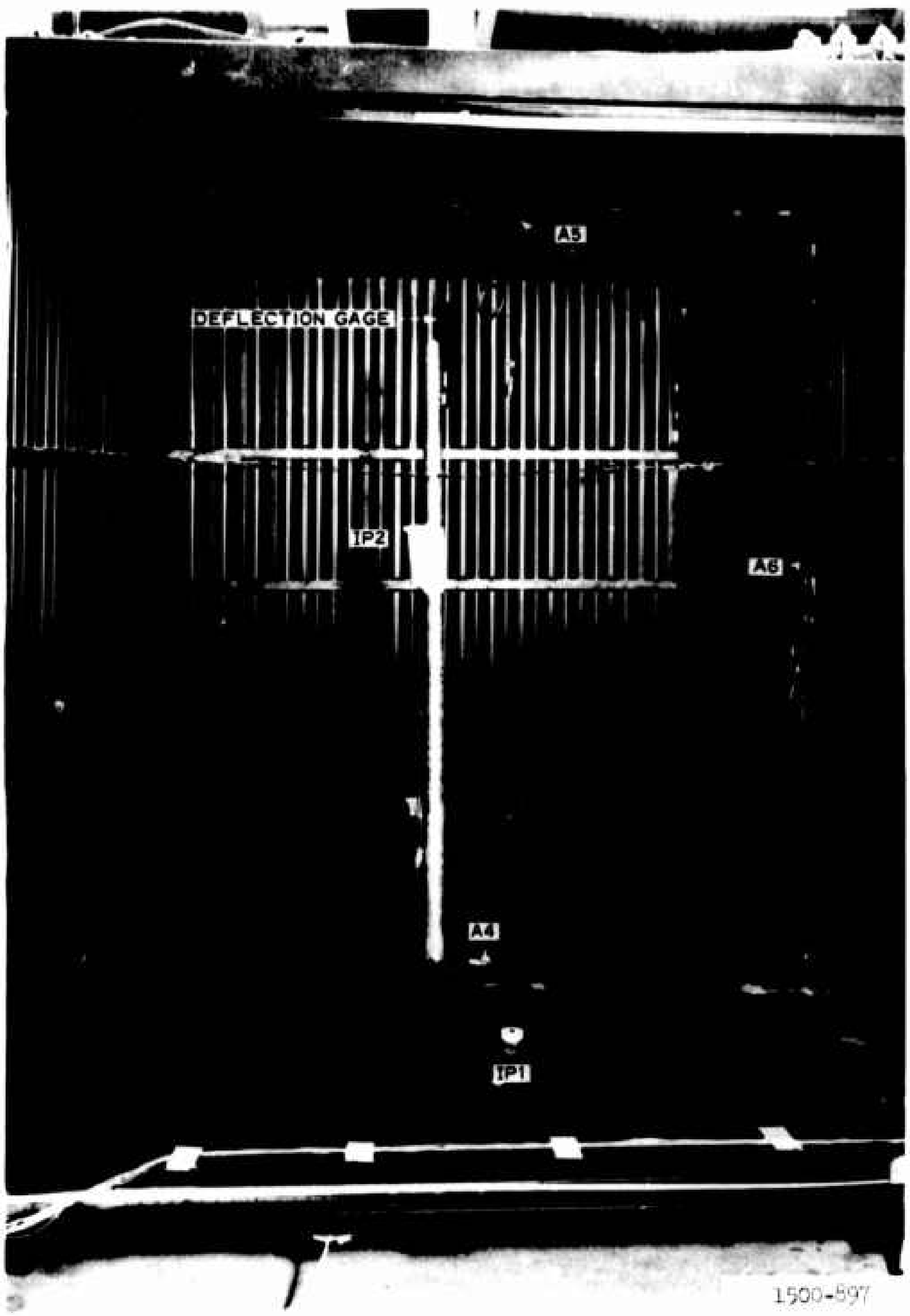


Figure 2.6 Container instrumentation.

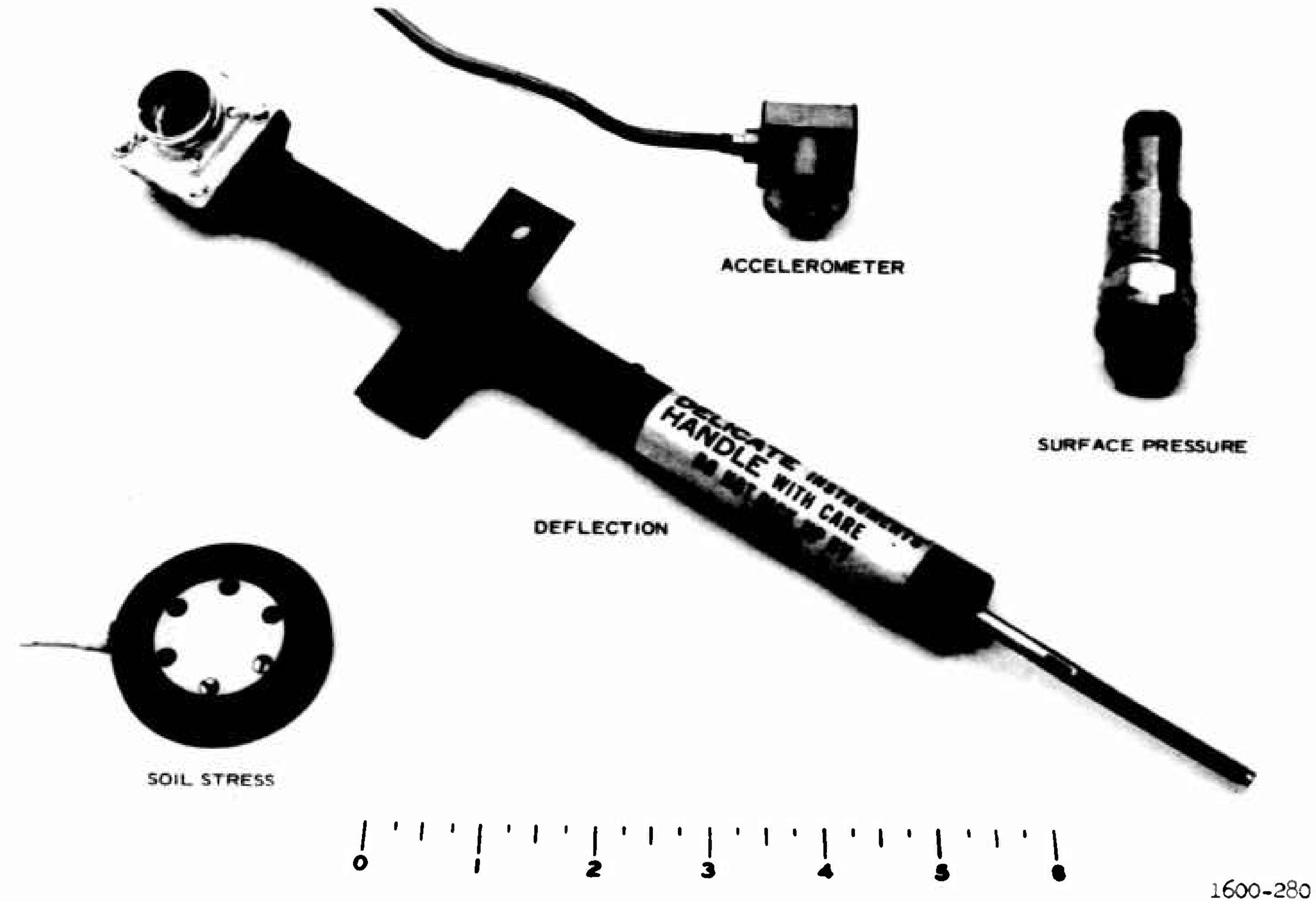
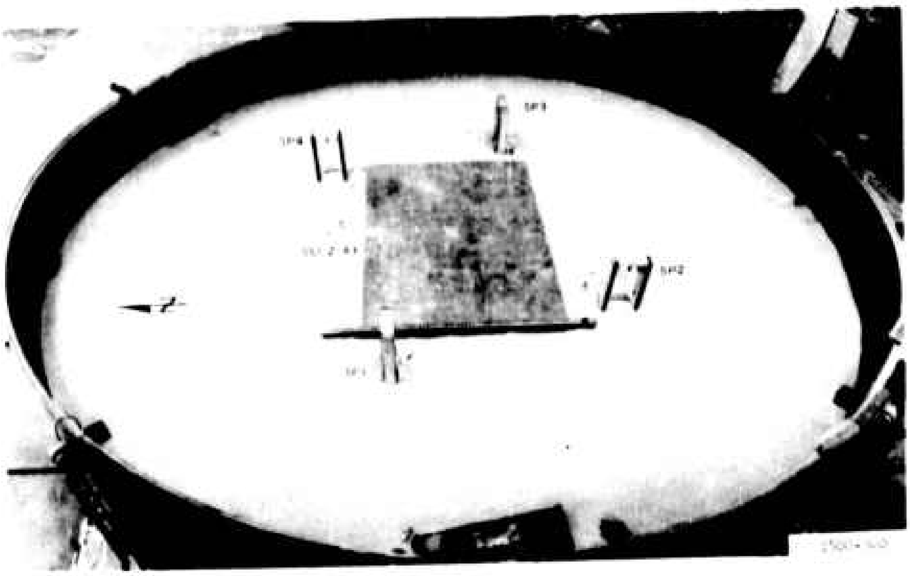
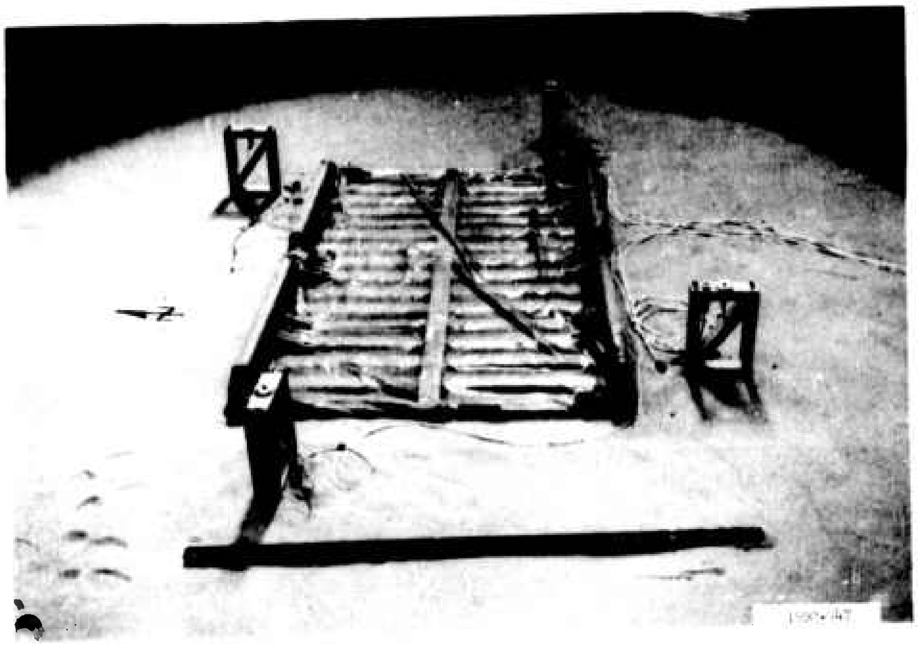


Figure 2.7 Transducers used in the test program.



a. Before tests 1 and 2 (base down).



b. Before test 3 (base up).

Figure 2.8 Container positioned in test chamber prior to final backfill placement.

CHAPTER 3

TEST RESULTS

3.1 VISUAL OBSERVATION OF DAMAGE

For the first test, the buried CONEX container was subjected to a surface pressure of 11 psi. After the shot, the container was uncovered and the damage observed. The container roof had sustained a permanent deformation of 3.2 inches at the center. A crease had formed at the rear edge (west) of the roof and extended approximately 3 feet toward the center. Buckling of three corrugations on the inside surface of the roof was observed. No welding failures were noted, and overall damage to the structure was assessed as moderate. The notable damage sustained by the structure as a result of Test 1 can be observed in Figure 3.1.

A second test was conducted, and the structure was subjected to a surface pressure of 34 psi. A severe shear-type failure of the structure roof occurred (Figure 3.2a). In addition, inward deformation of the sides, back, and front was noted (Figure 3.2b). After the CONEX was uncovered, the roof, which had been blown to the floor, was removed. The damaged roof is shown in Figure 3.2c. Note that the inside corrugated layer was flattened by the blast. Damage to the structure bottom was minor (Figure 3.2d).

A third test was conducted on an inverted CONEX placed in the LBLG. A pressure of 15 psi was measured at the surface. Damage to the structure was moderate. A level survey conducted on the container showed a 2.2-inch permanent deflection at the roof center (Figure 3.3).

3.2 PRESENTATION OF DATA

To facilitate data reduction, all recorded analog data were digitized at a sampling rate of 12 kc and processed on a central processor. Due to inconsistencies in the recorded stress-time histories for the free-field stress gages (SS gages), the records for these gages have been eliminated. However, selected pressure, displacement, acceleration, and strain results are presented.

<u>3.2.1 Pressure Data</u>. Typical surface pressure-time and internal pressure-time histories for the three tests are presented in Figures 3.4 and 3.5, respectively. The mean pressures shown in these figures were determined in the following manner: first, a straight line was constructed through the impulse-time histories (plots not shown) for all pressure records of

each test, second, the slope (impulse divided by time) of this straight line was considered to be the mean pressure for each gage signature; finally, the mean pressures for each test were arithmetically averaged.

3.2.2 Acceleration Data. Structure and free-field accelerations along with the velocities and displacements are presented in Figures 3.6 through 3.21. The velocities and displacements were obtained by single and double integrations of the acceleration-time histories. A uniform baseline shift with a magnitude equal to the average acceleration was applied to each acceleration trace to adjust for baseline offsets.

3.2.3 Strain Data. Selected strain-time signatures for Tests 1 through 3 are shown in Figures 3.22 through 3.24.

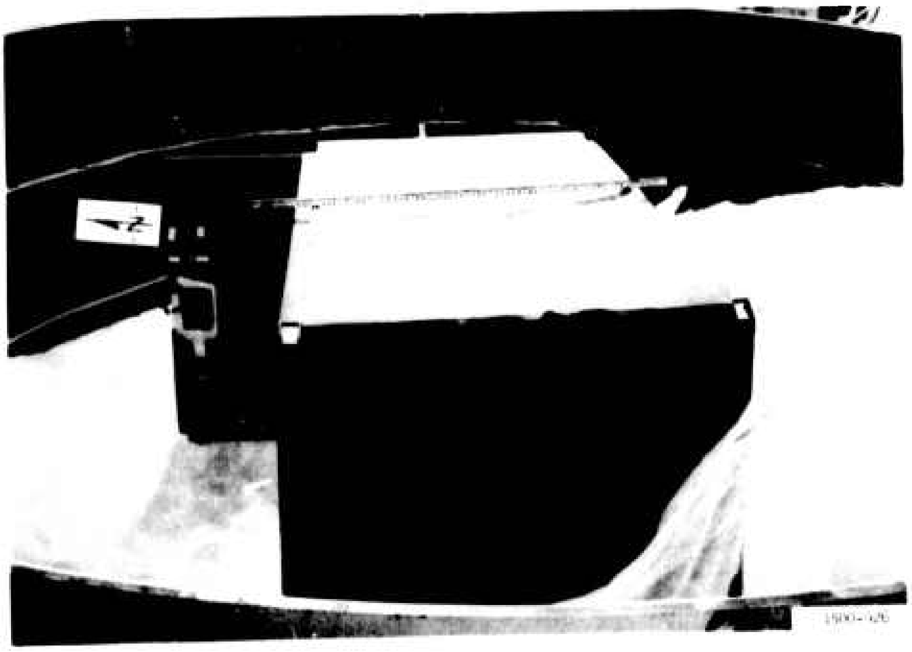
3.2.4 Deflection Data. Relative displacement between the CONEX roof and floor for Test 1 is shown in Figure 3.25. A summary of peak displacements at the center of the roof as recorded for Tests 1 and 3 is presented in Table 3.1.

3.2.5 Structure Material Properties. Four tensile specimens were cut from different locations on the CONEX and tested statically. A composite stress-strain curve is shown in Figure 3.26.

TABLE 3.1 PEAK DISPLACEMENTS OF CONEX ROOF

Test No.	Mean Pressure	Peak Midpoint Displacement		
		Dynamic[a]	Permanent[b]	Relative[c]
	psi	inches	inches	inches
1	11	4.9	3.2	3.5
3	15	3.1	2.2	–

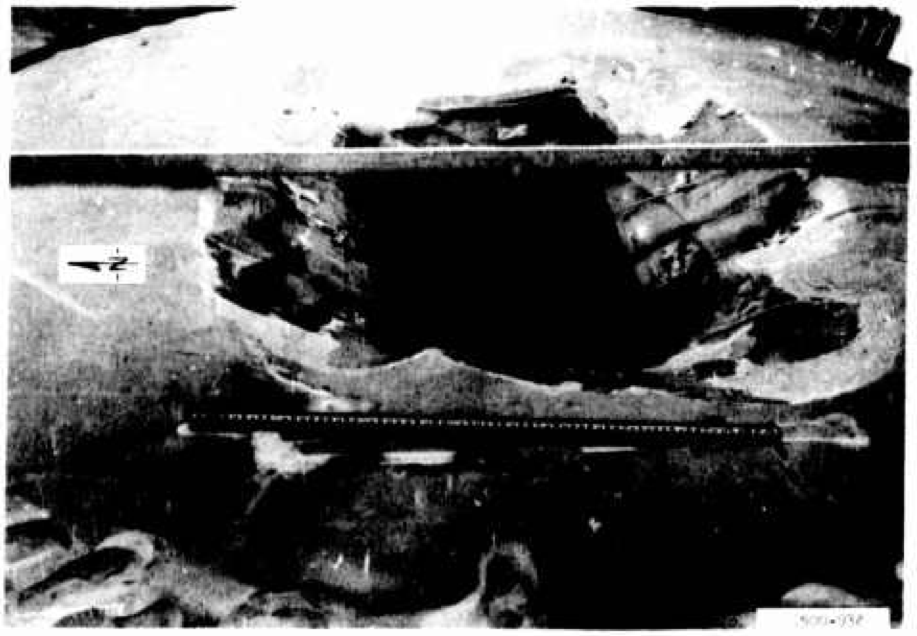
[a] Double integration of accelerometer A5.
[b] Preshot and posttest level survey.
[c] Deflection gage CD1.



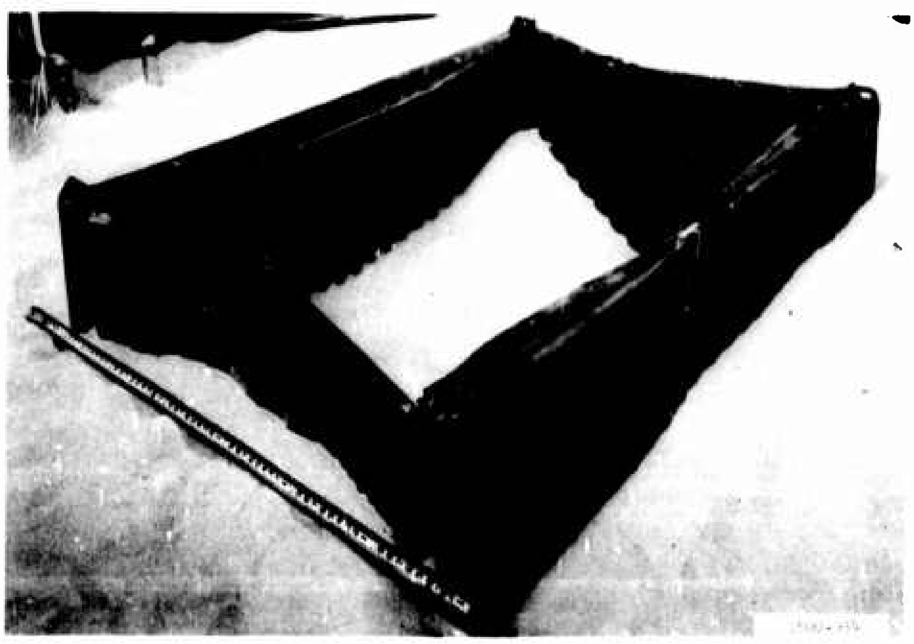
a. Roof deflection and damage.

b. Interior view of roof buckling.

Figure 3.1 Damage to CONEX; Test 1.



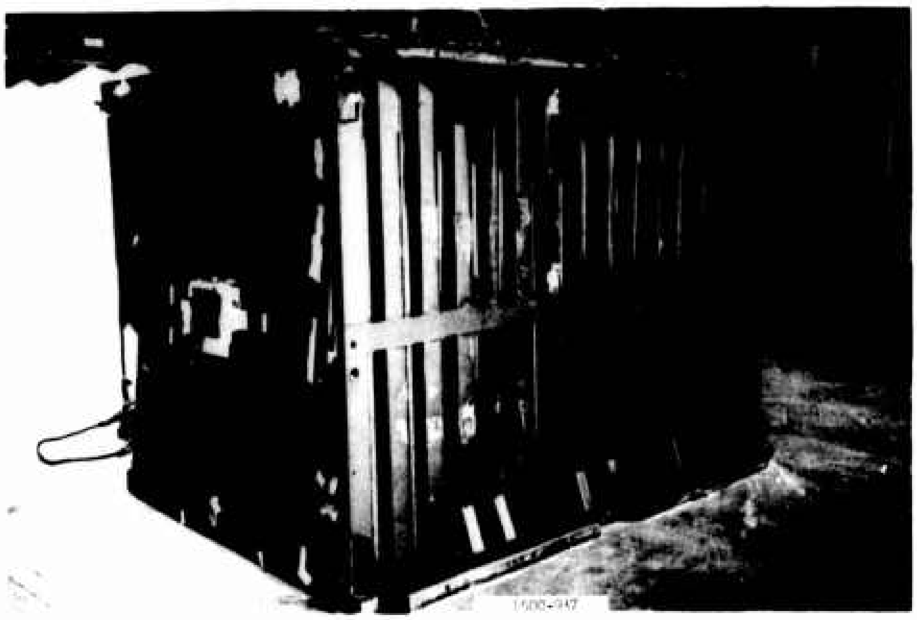
a. Posttest view prior to excavation.



b. Partially uncovered container (top is buried inside container).

Figure 3.2 Damage to CONEX; Test 2 (Sheet 1 of 2).

c. CONEX top after removal (bottom layer was corrugated but was flattened by blast wave.



d. Minor damage to bottom.

Figure 3.2 (Sheet 2 of 2).

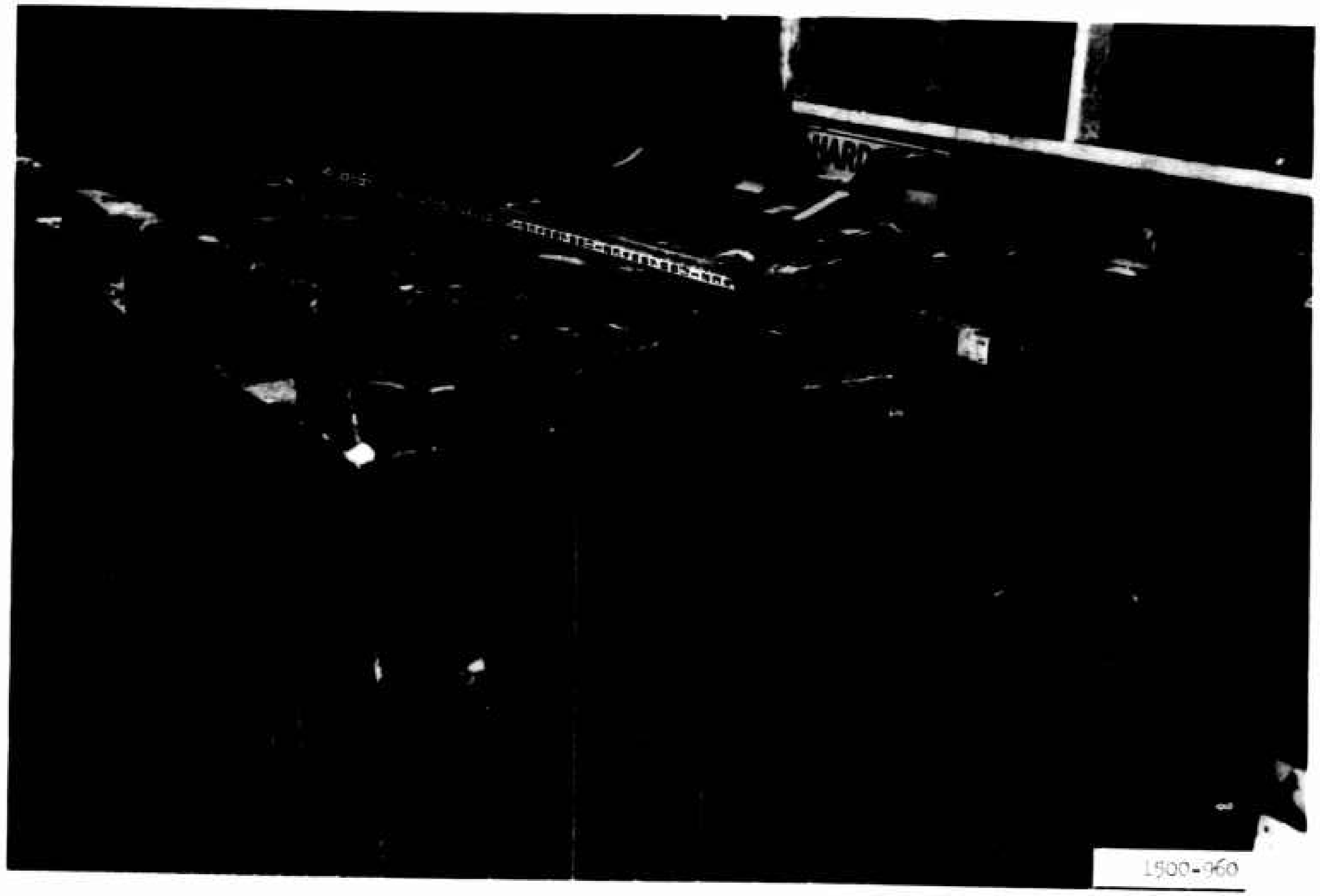


Figure 3.3 Damage to CONEX; Test 3.

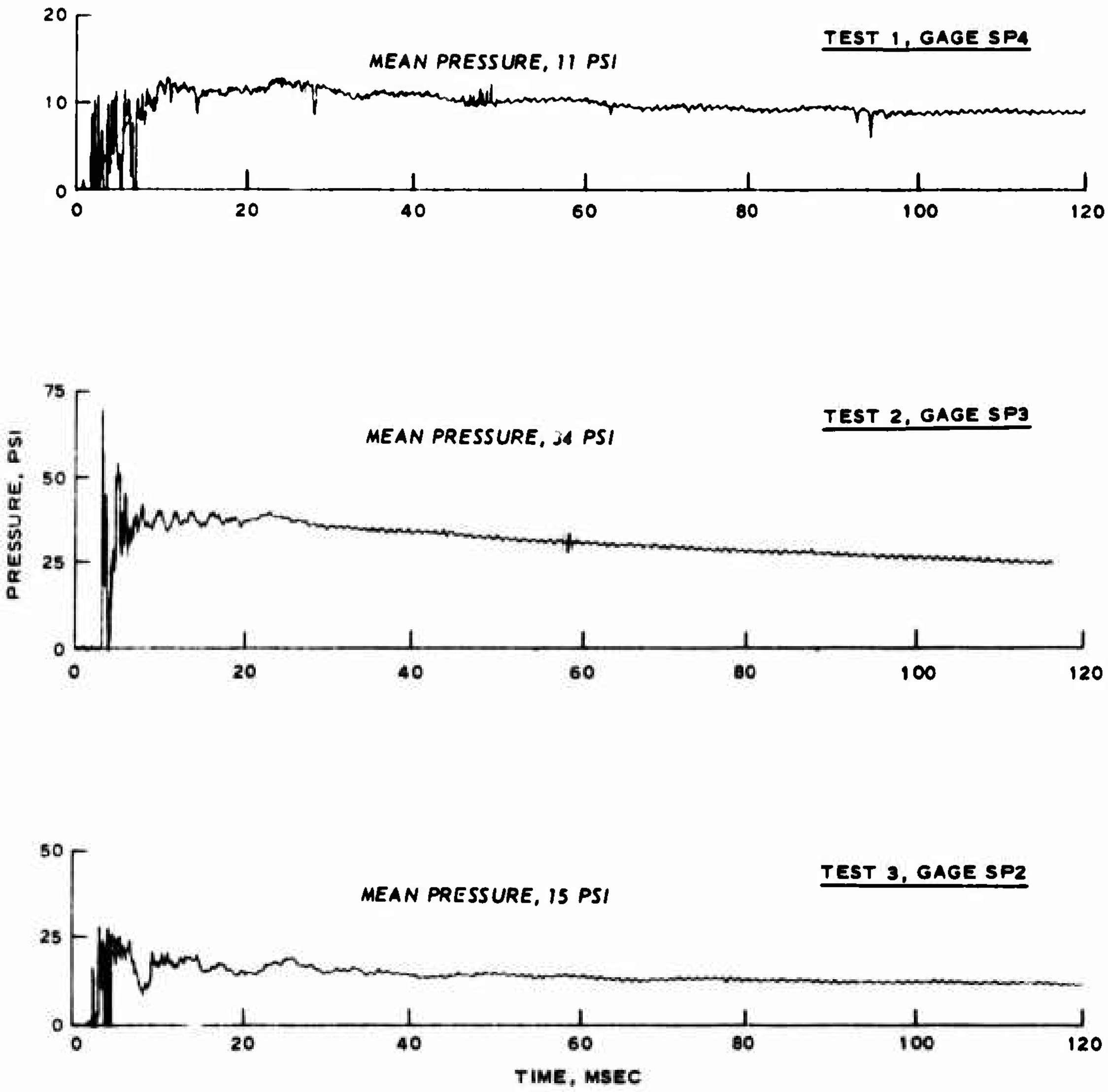


Figure 3.4 Typical surface pressure histories.

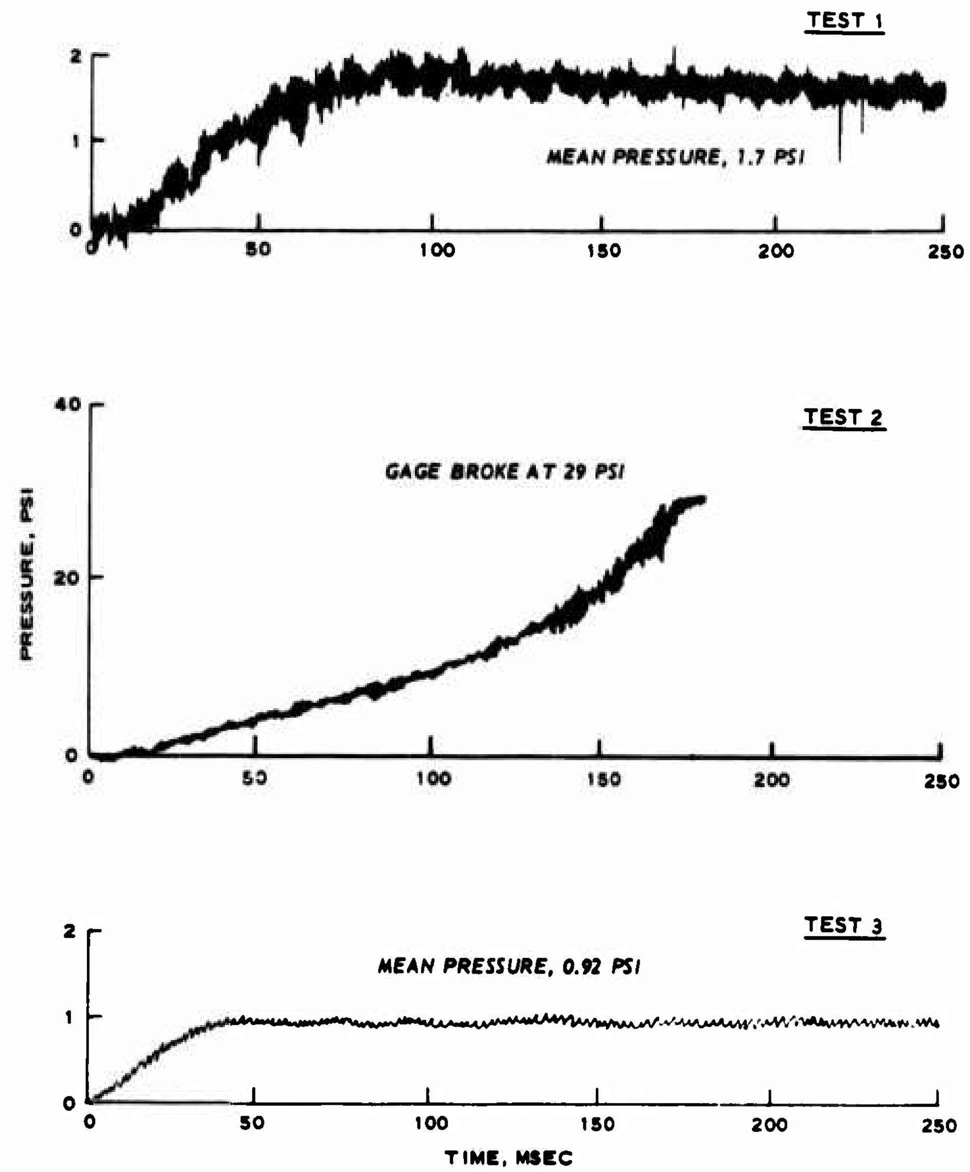


Figure 3.5 Typical internal pressure histories; Gage IP1.

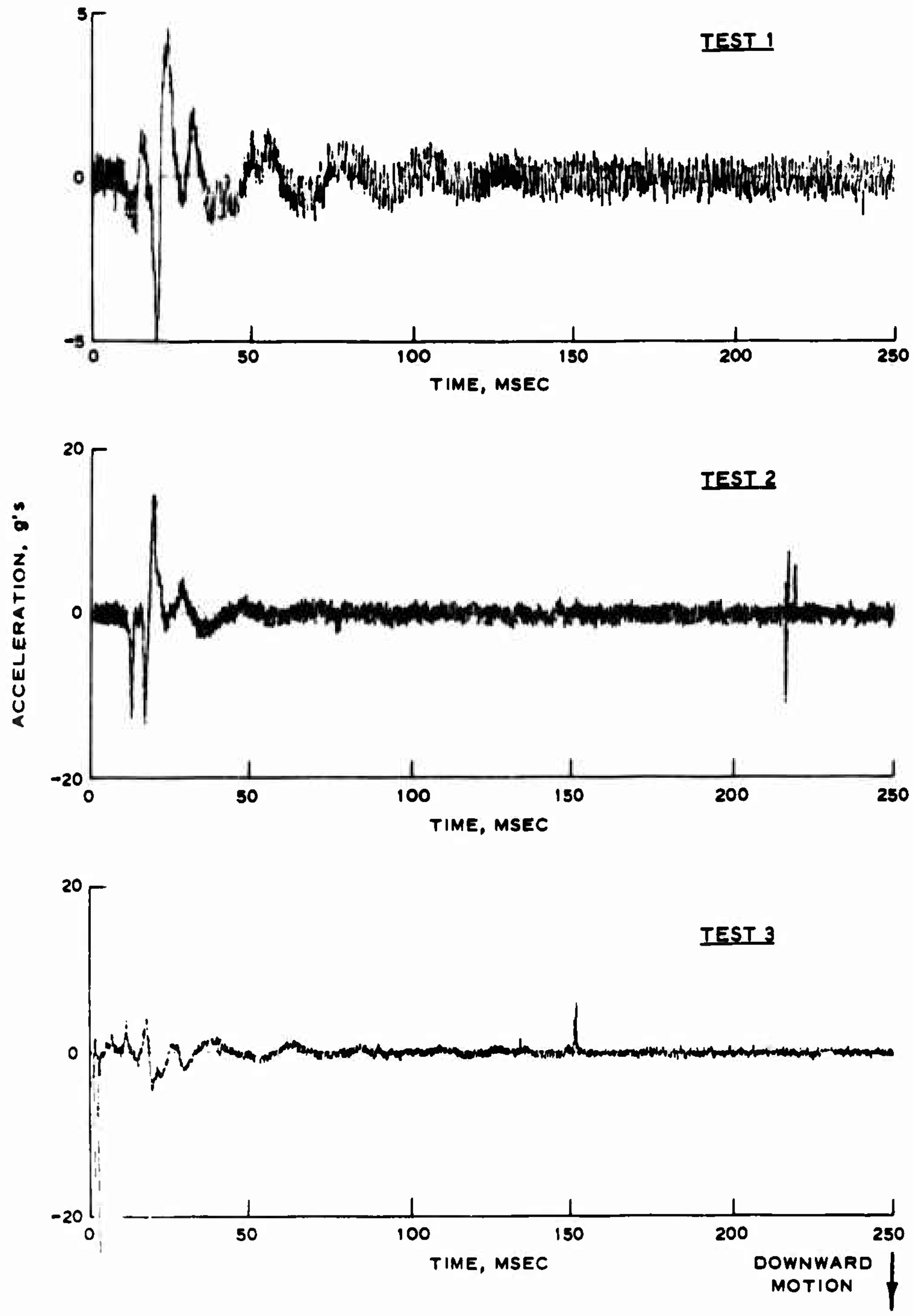


Figure 3.6 Free-field acceleration at floor level; Gage A1, Tests 1 through 3.

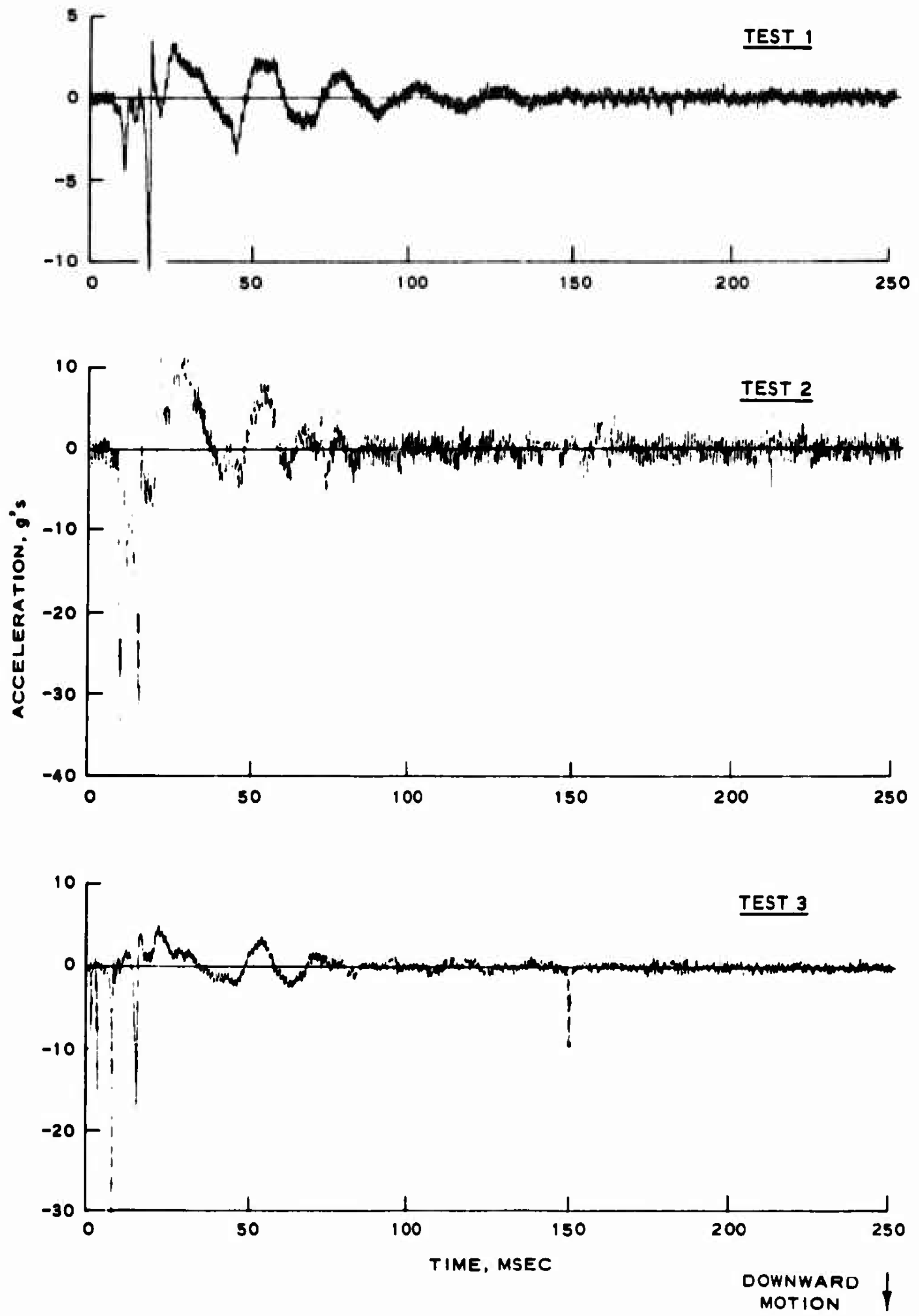


Figure 3.7 Free-field acceleration at midstructure depth; Gage A2, Tests 1 through 3.

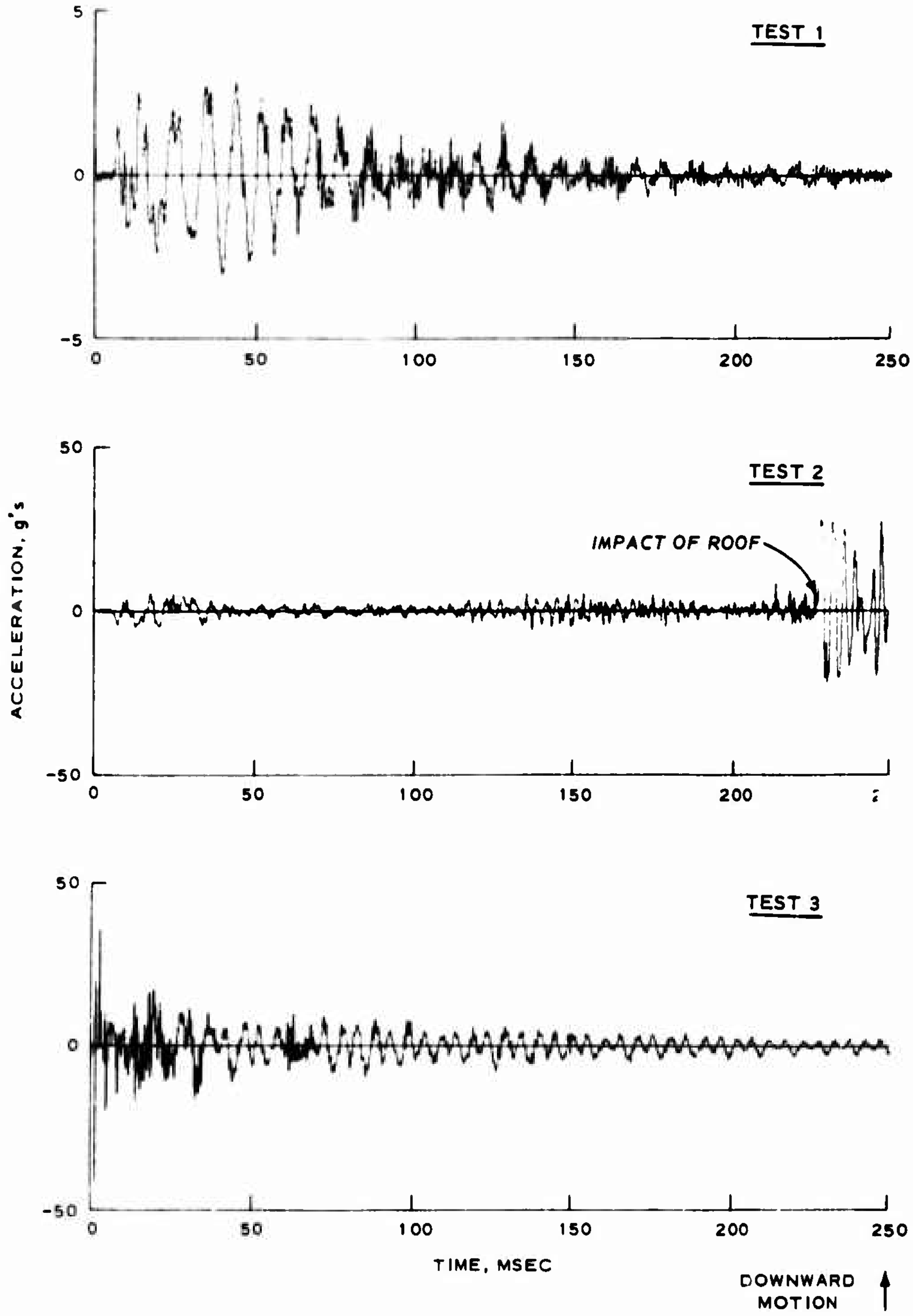


Figure 3.8 Acceleration at CONEX floor; Gage A4, Tests 1 through 3.

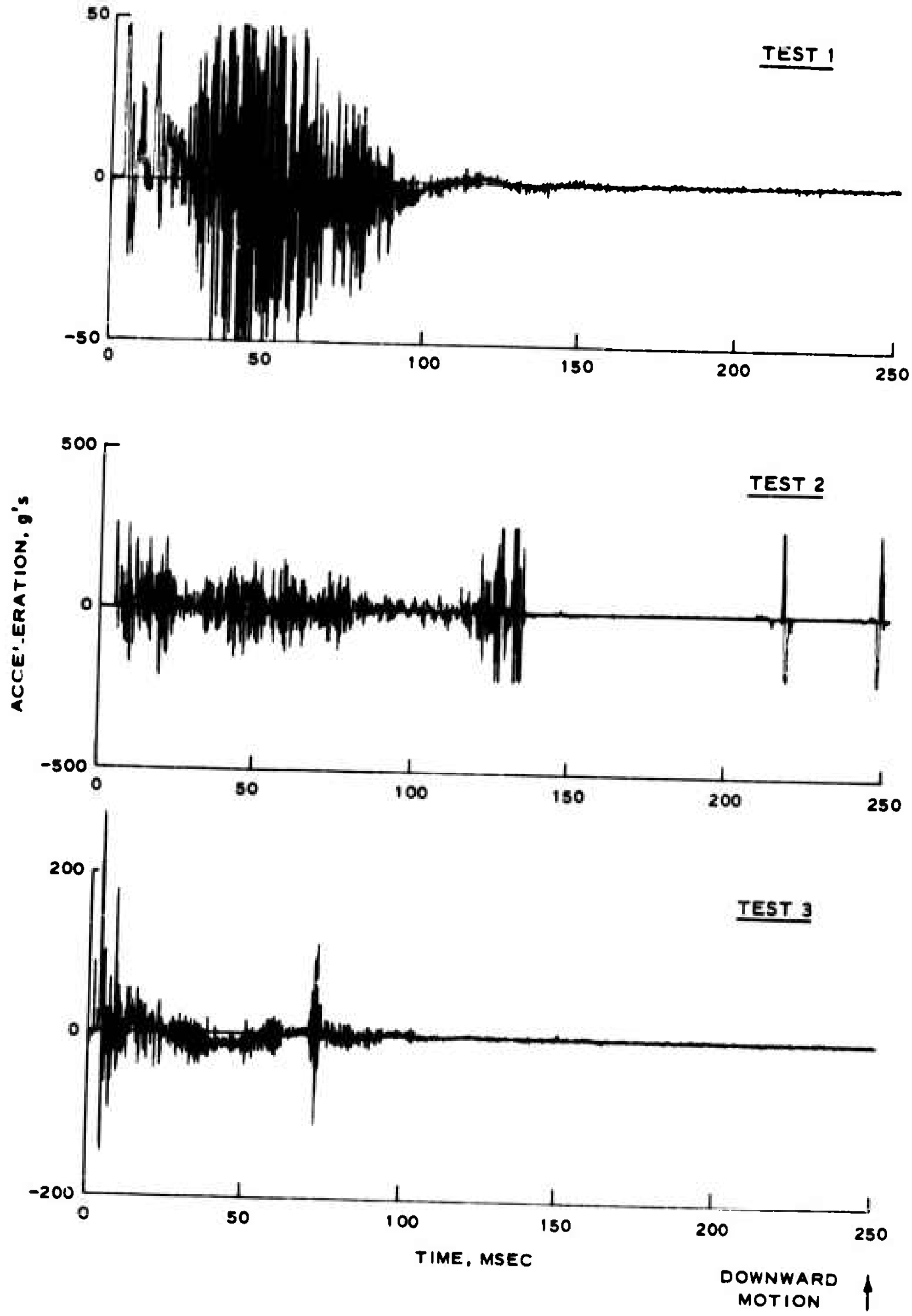


Figure 3.9 Acceleration at CONEX roof; Gage A5, Tests 1 through 3.

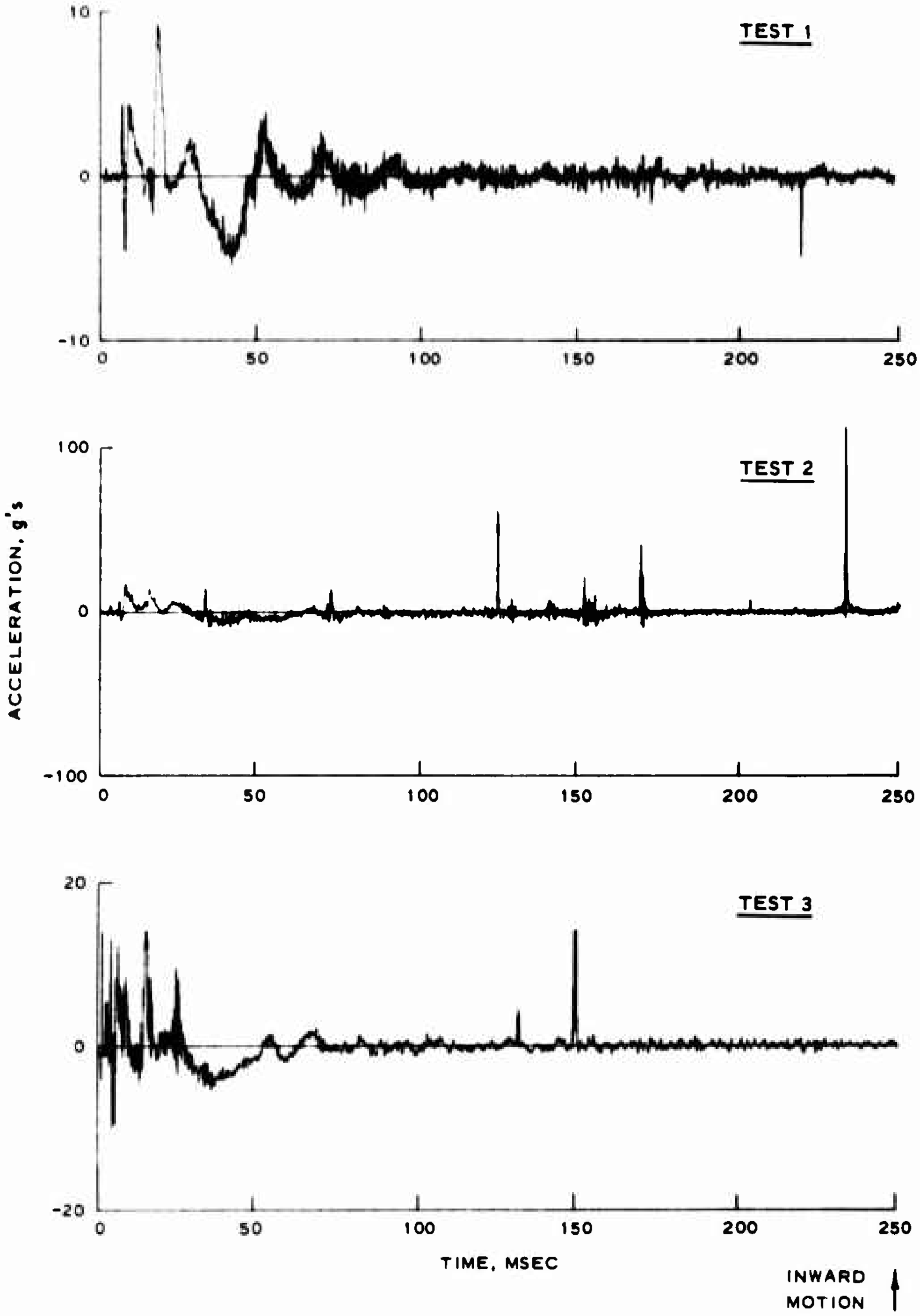


Figure 3.10 Acceleration at CONEX sidewall; Gage A6, Tests 1 through 3.

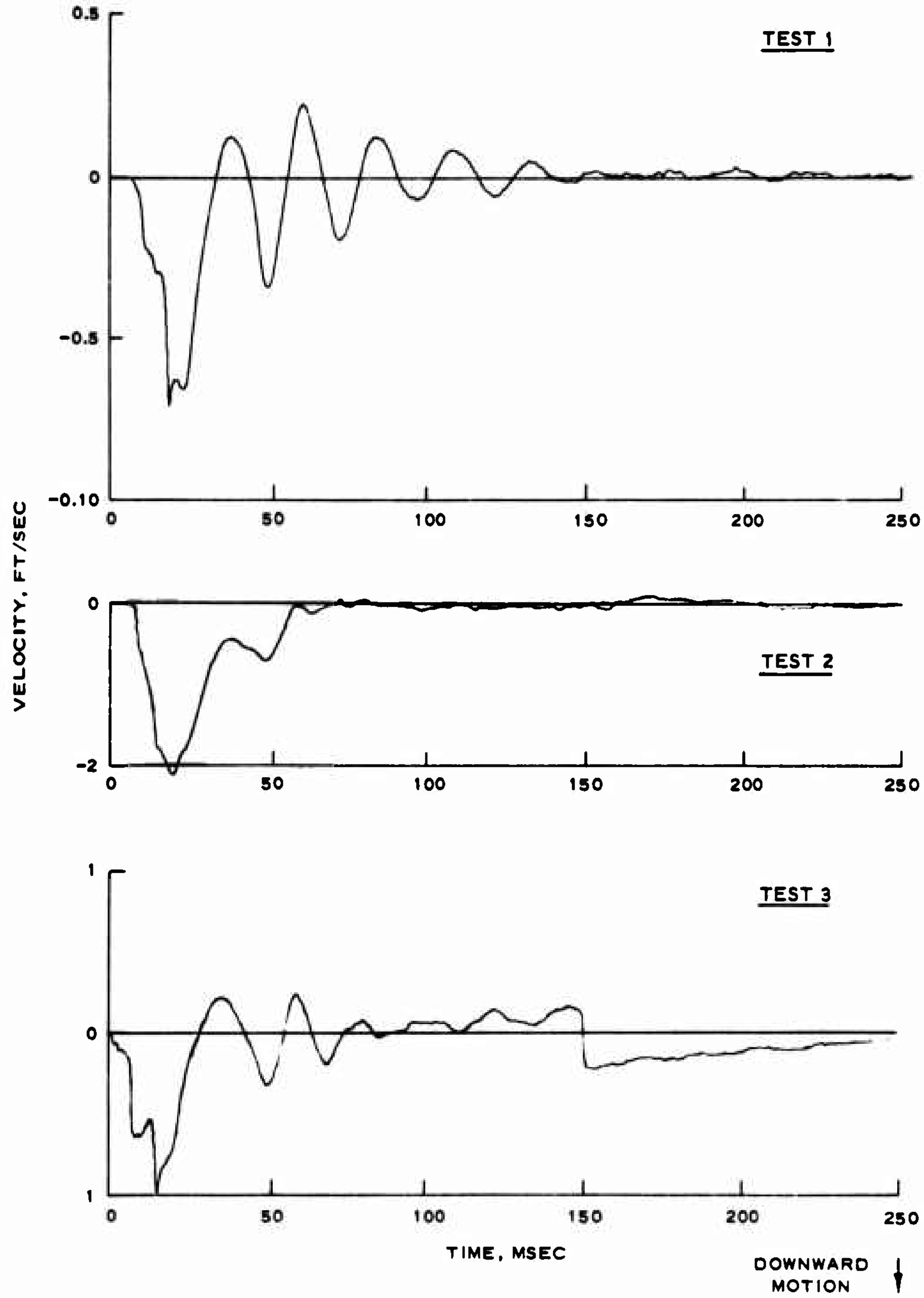


Figure 3.11 Free-field velocity at floor level; Gage A1, Tests 1 through 3.

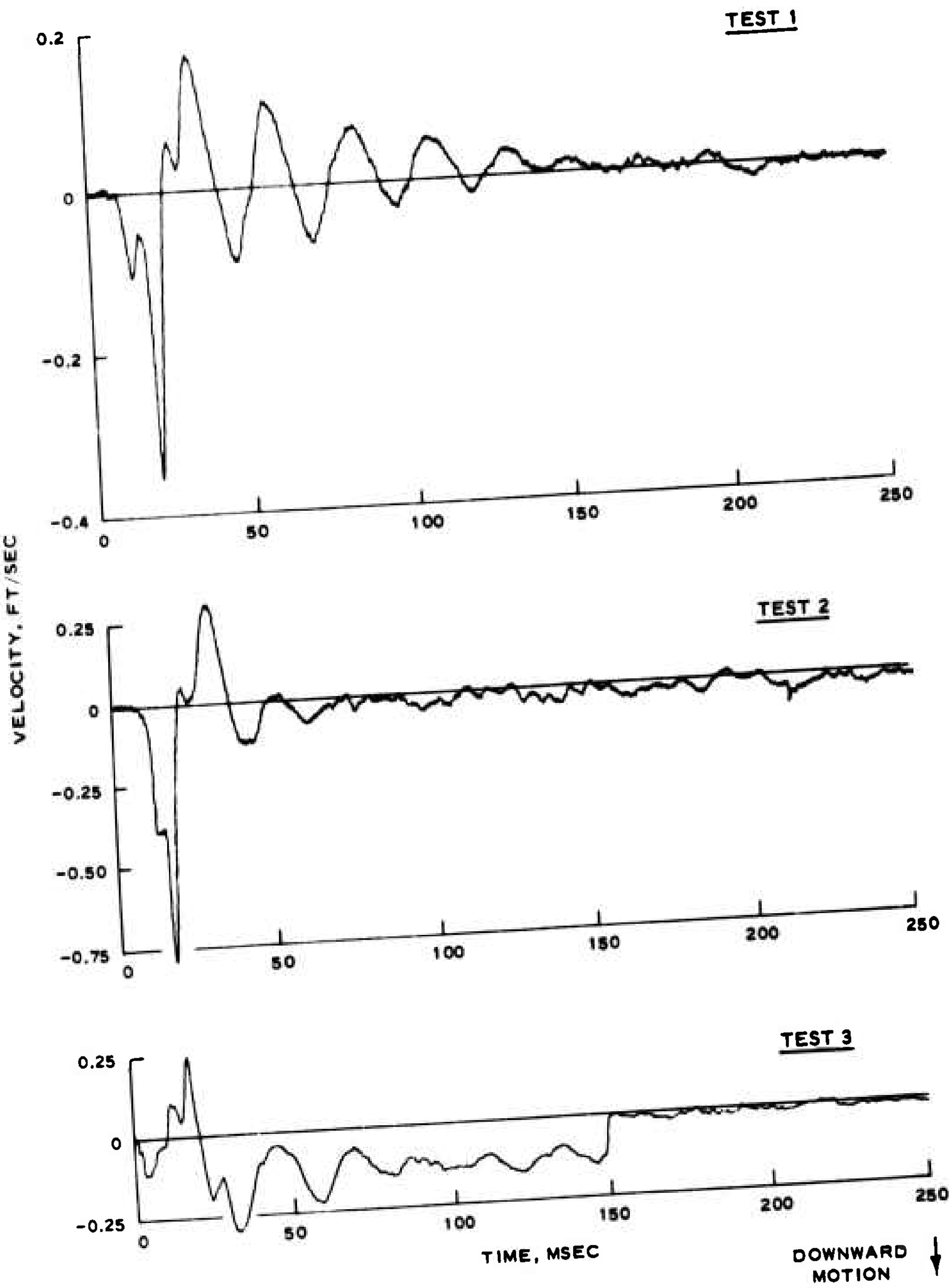


Figure 3.12 Free-field velocity at midstructure depth; Gage A2, Tests 1 through 3.

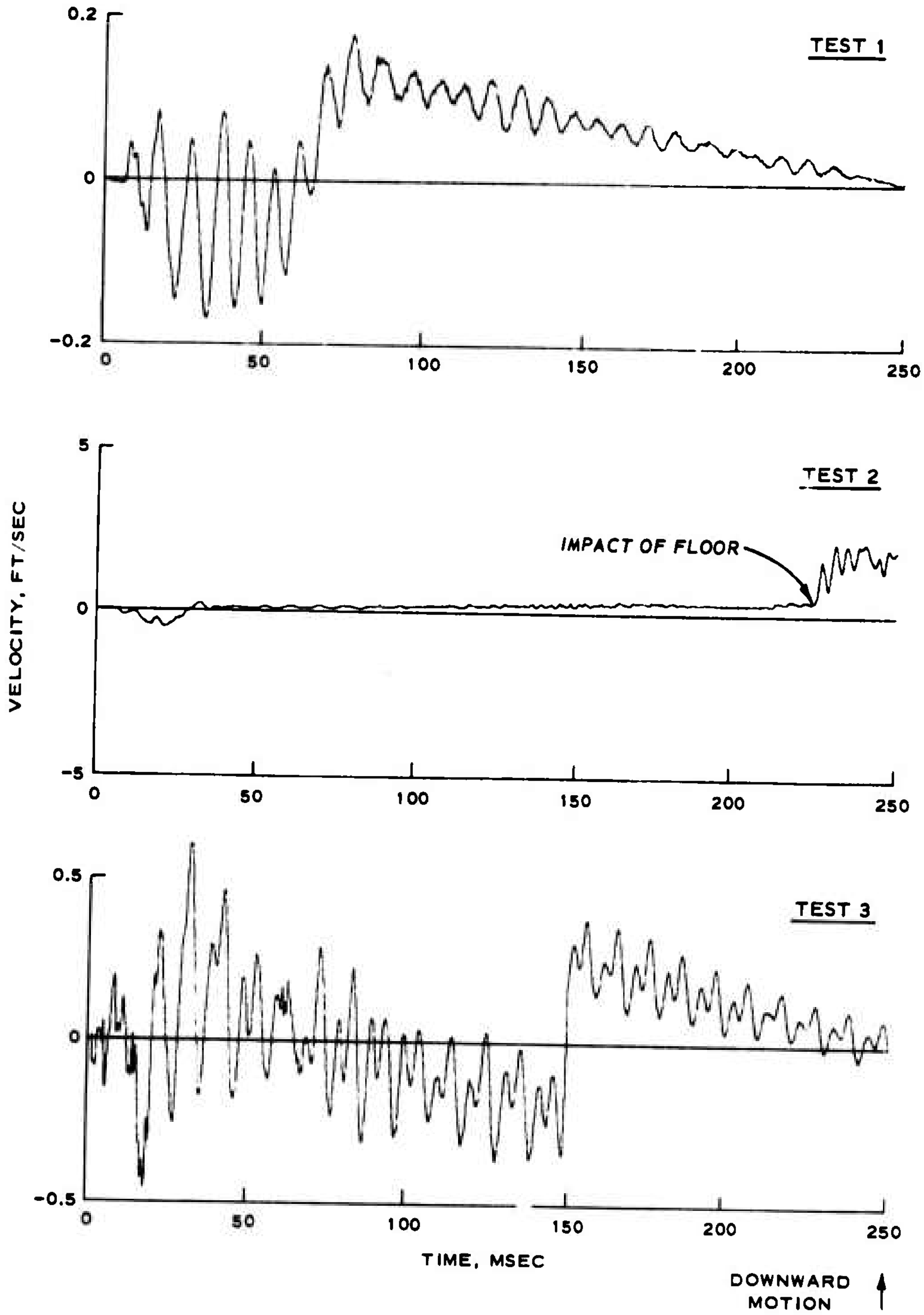


Figure 3.13 Velocity at CONEX floor; Gage A4, Tests 1 through 3.

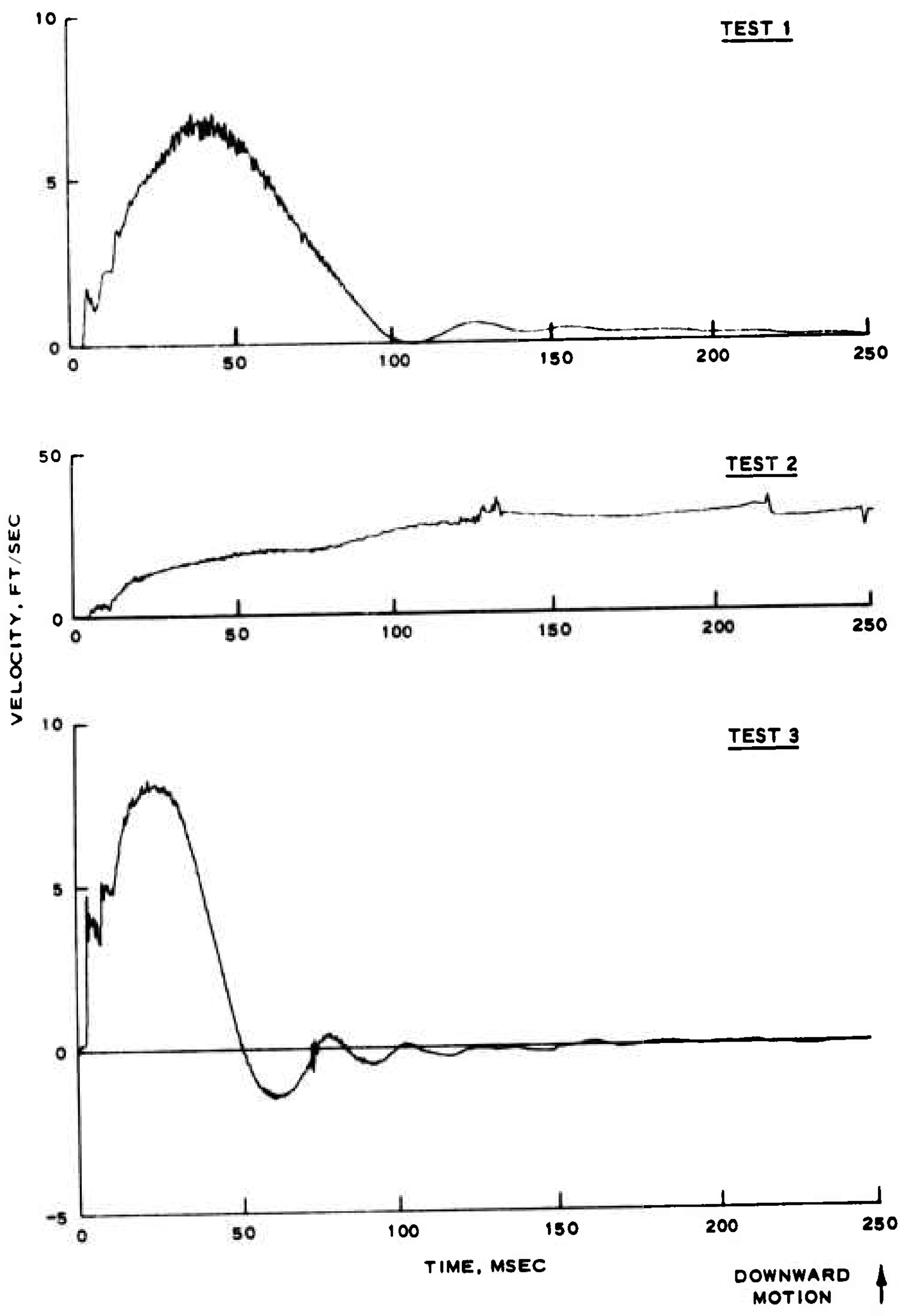


Figure 3.14 Velocity at CONEX roof; Gage A5, Tests 1 through 3.

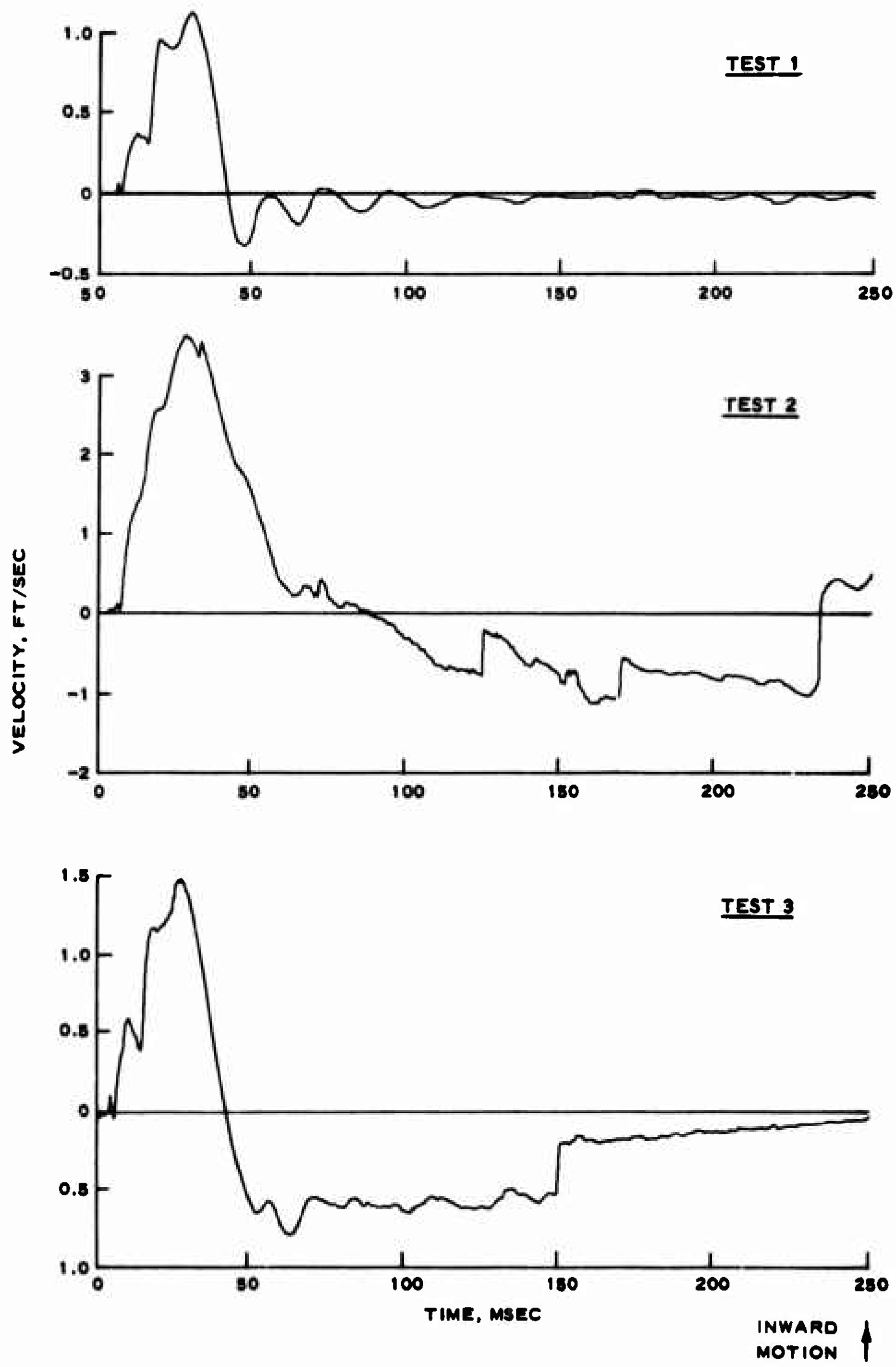


Figure 3.15 Velocity at CONEX sidewall; Gage A6, Tests 1 through 3.

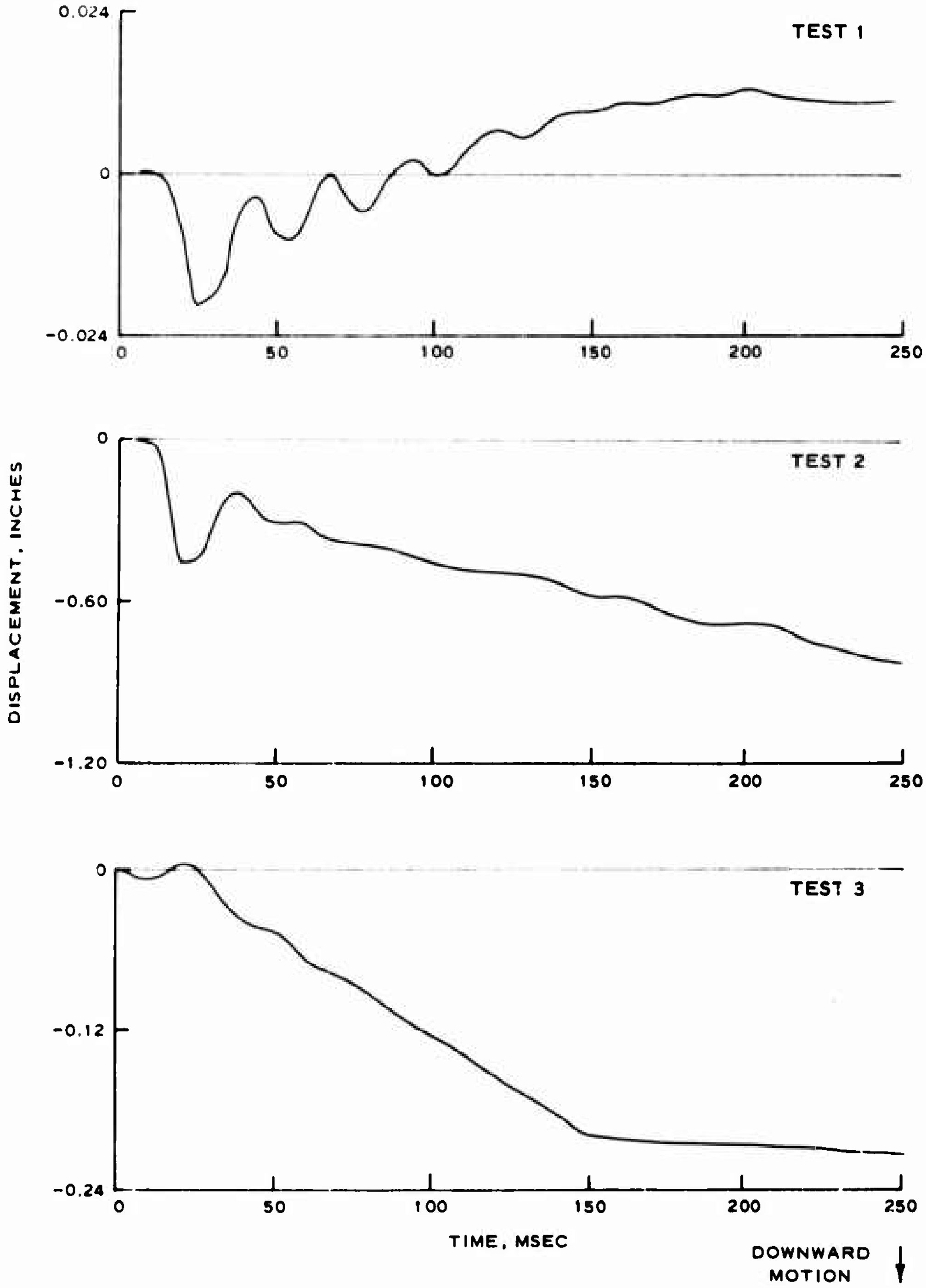


Figure 3.16 Free-field displacement at floor level; Gage A1, Tests 1 through 3.

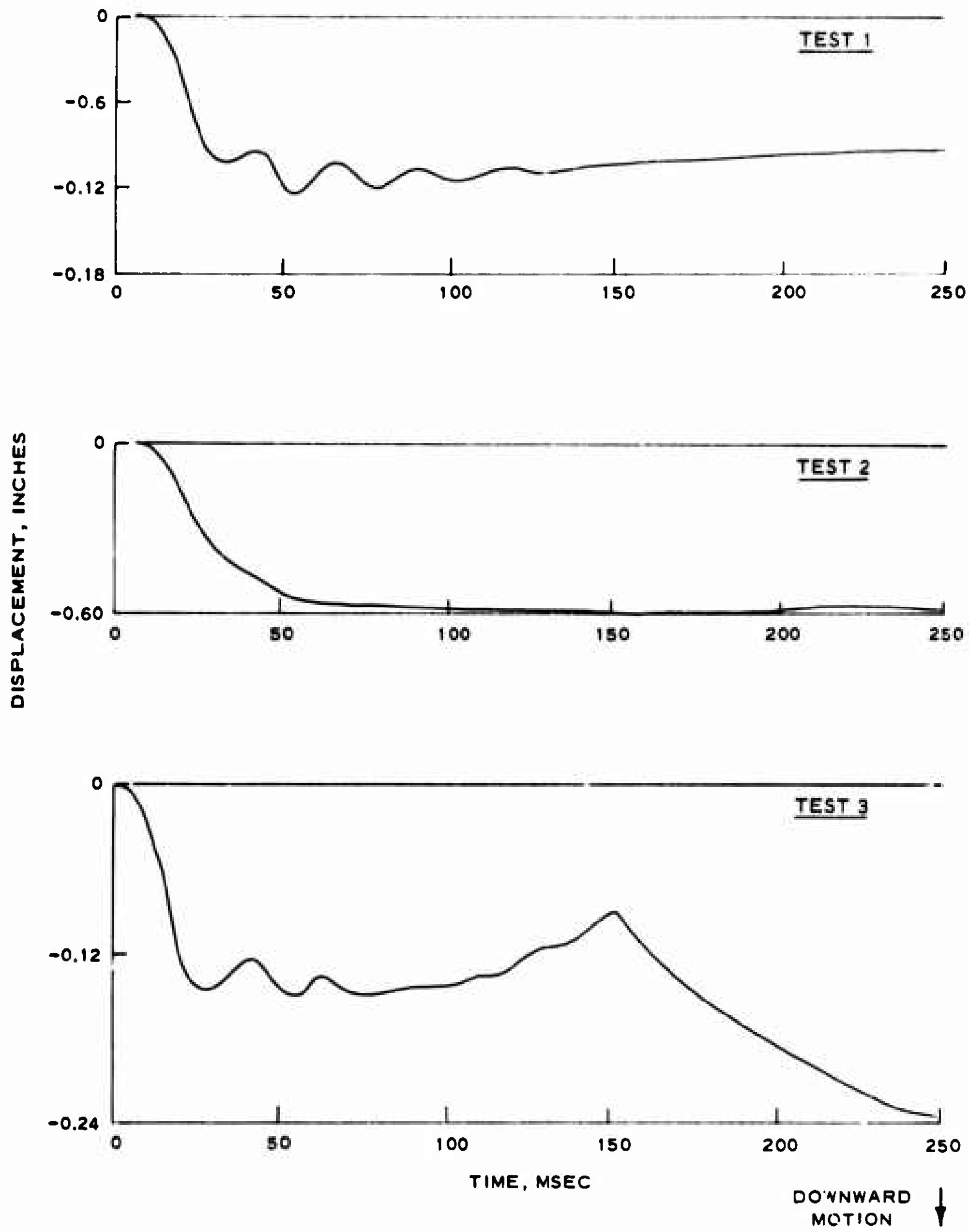


Figure 3.17 Free-field displacement at midstructure depth; Gage A2, Tests 1 through 3.

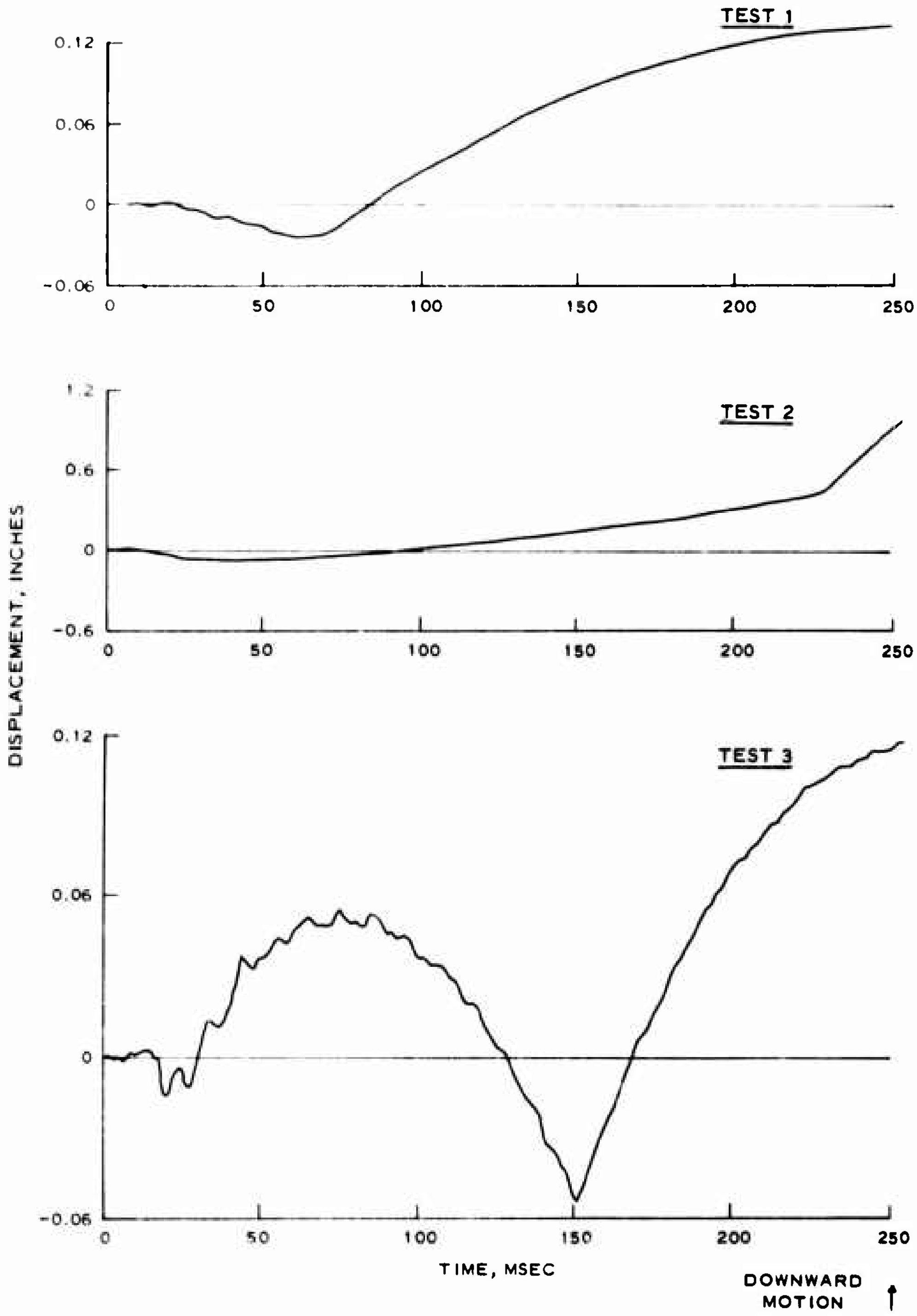


Figure 3.18 Displacement at CONEX floor; Gage A4, Tests 1 through 3.

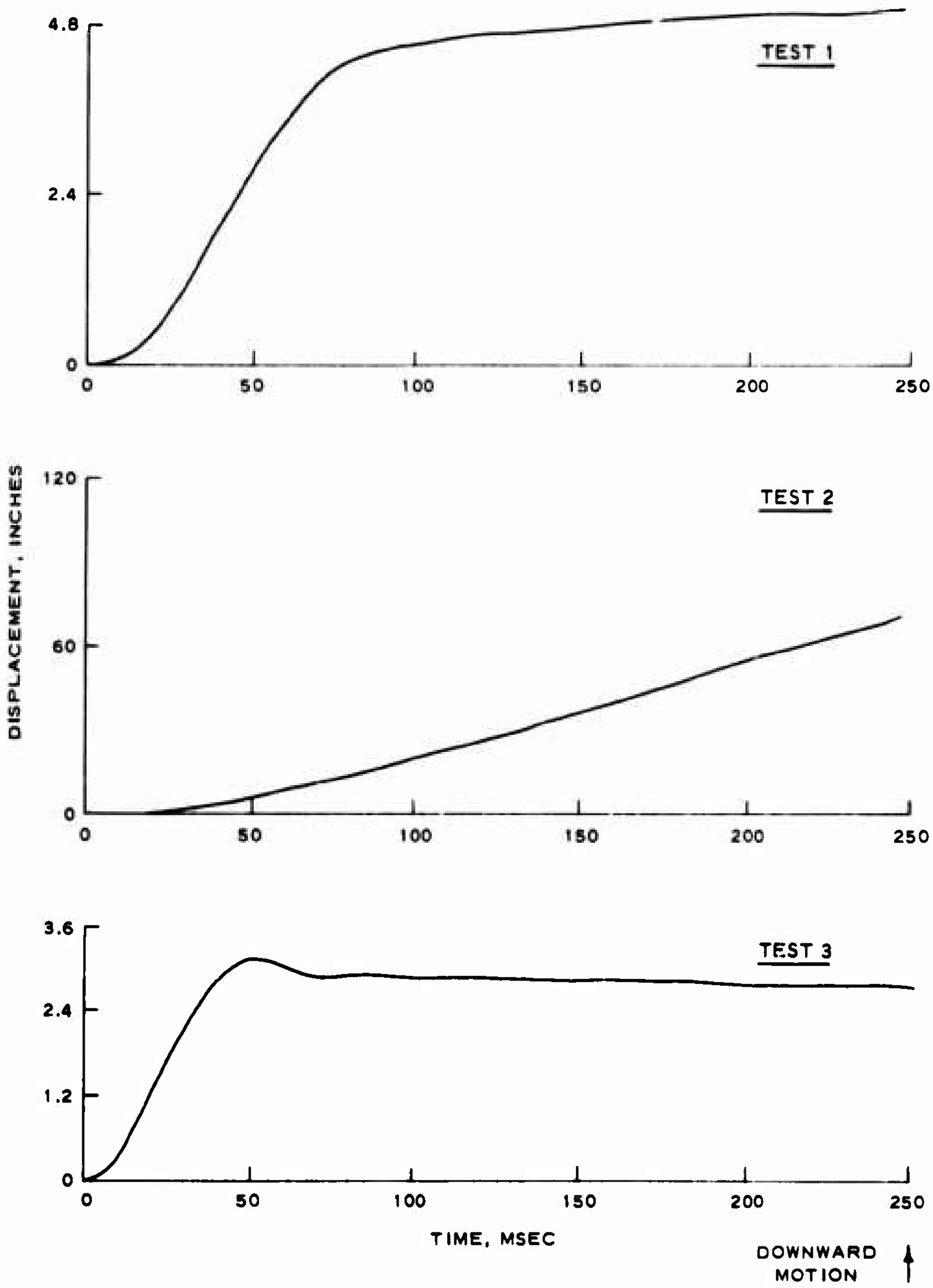


Figure 3.19 Displacement at CONEX roof; Gage A5, Tests 1 through 3.

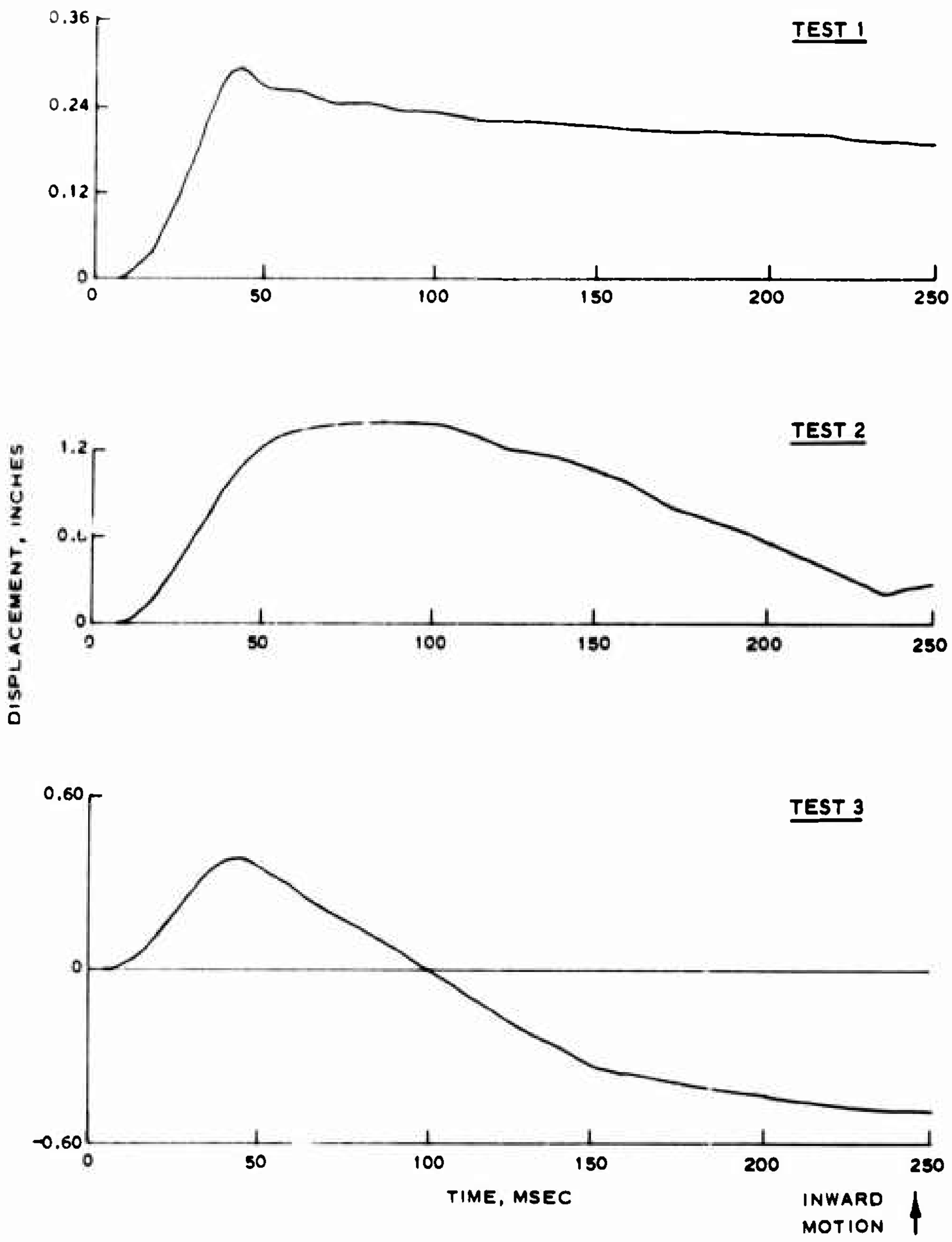


Figure 3.20 Displacement at CONEX sidewall; Gage A6, Tests 1 through 3.

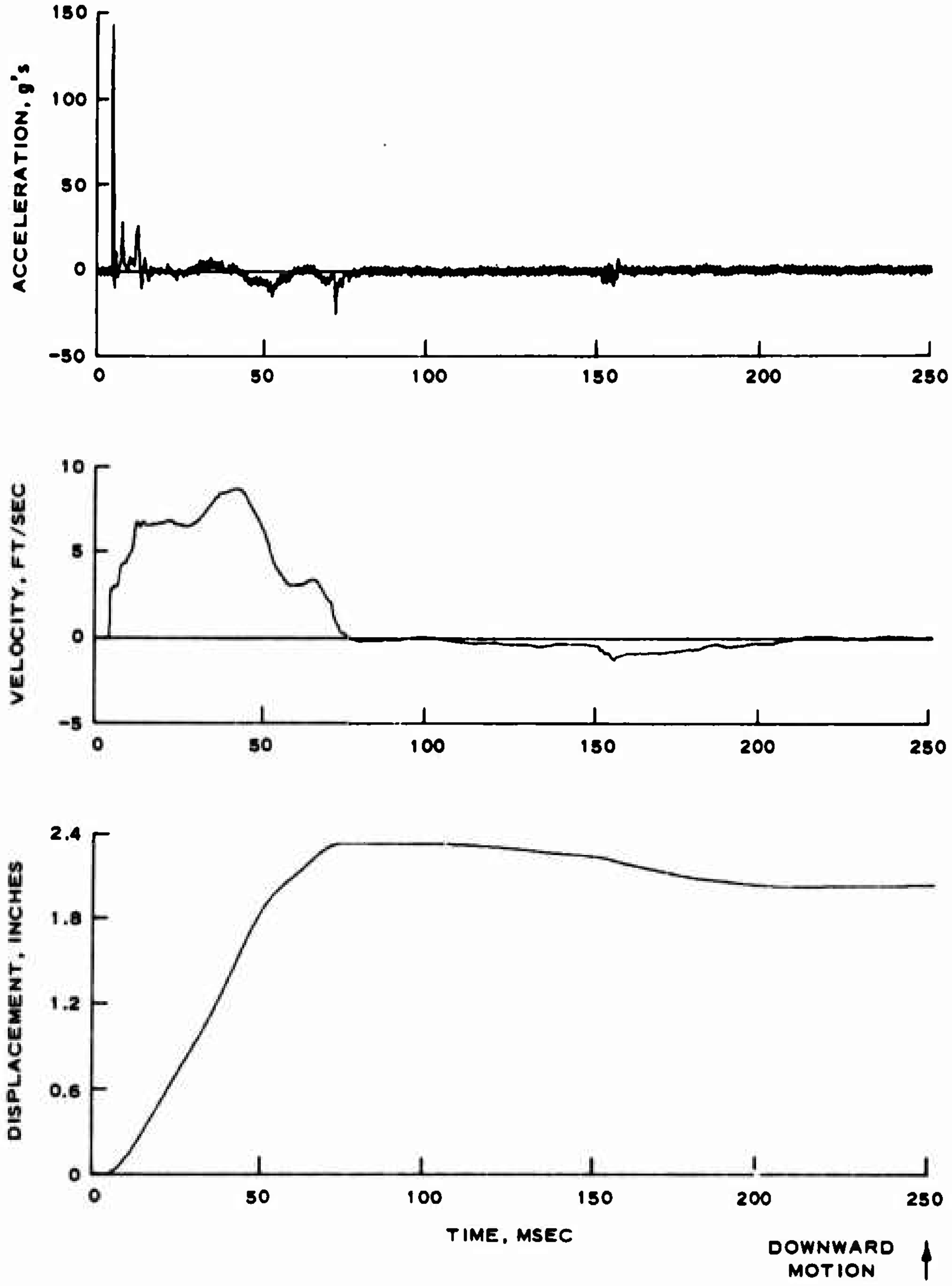


Figure 3.21 Free-field acceleration, velocity, and displacement at roof level; Gage A3, Test 2.

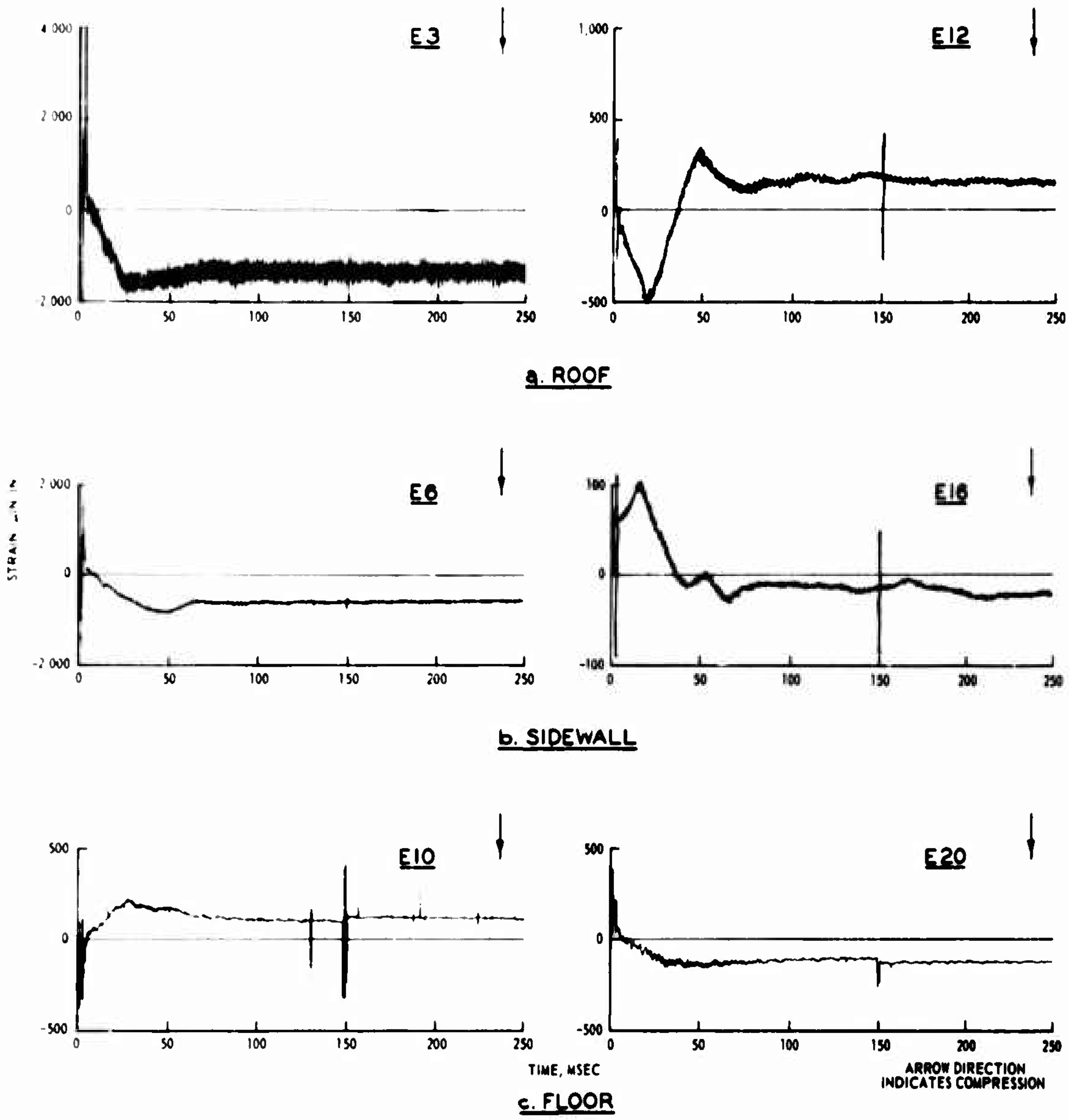


Figure 3.22 Selected strain gage signatures; Test 1.

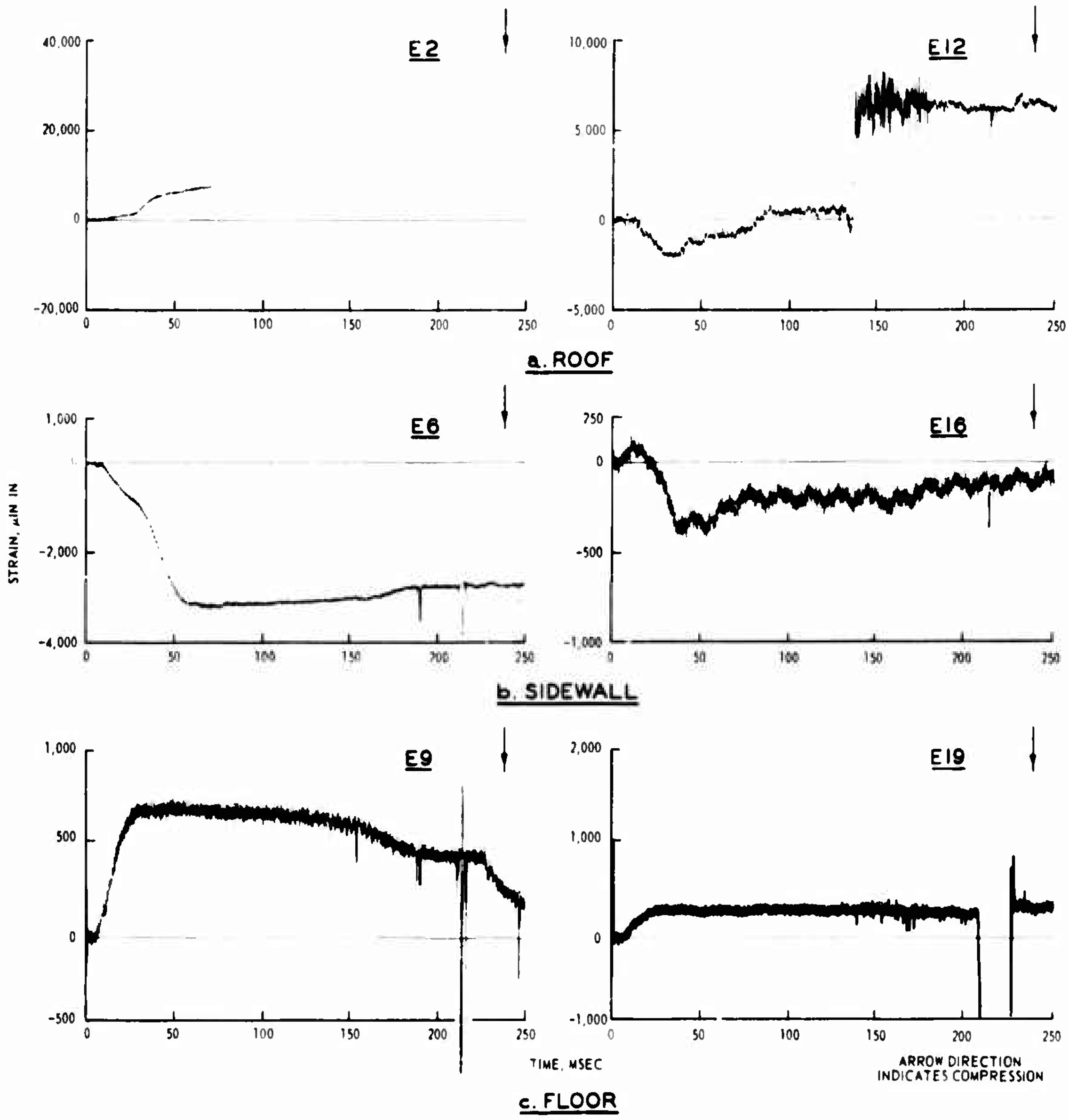


Figure 3.23 Selected strain gage signatures; Test 2.

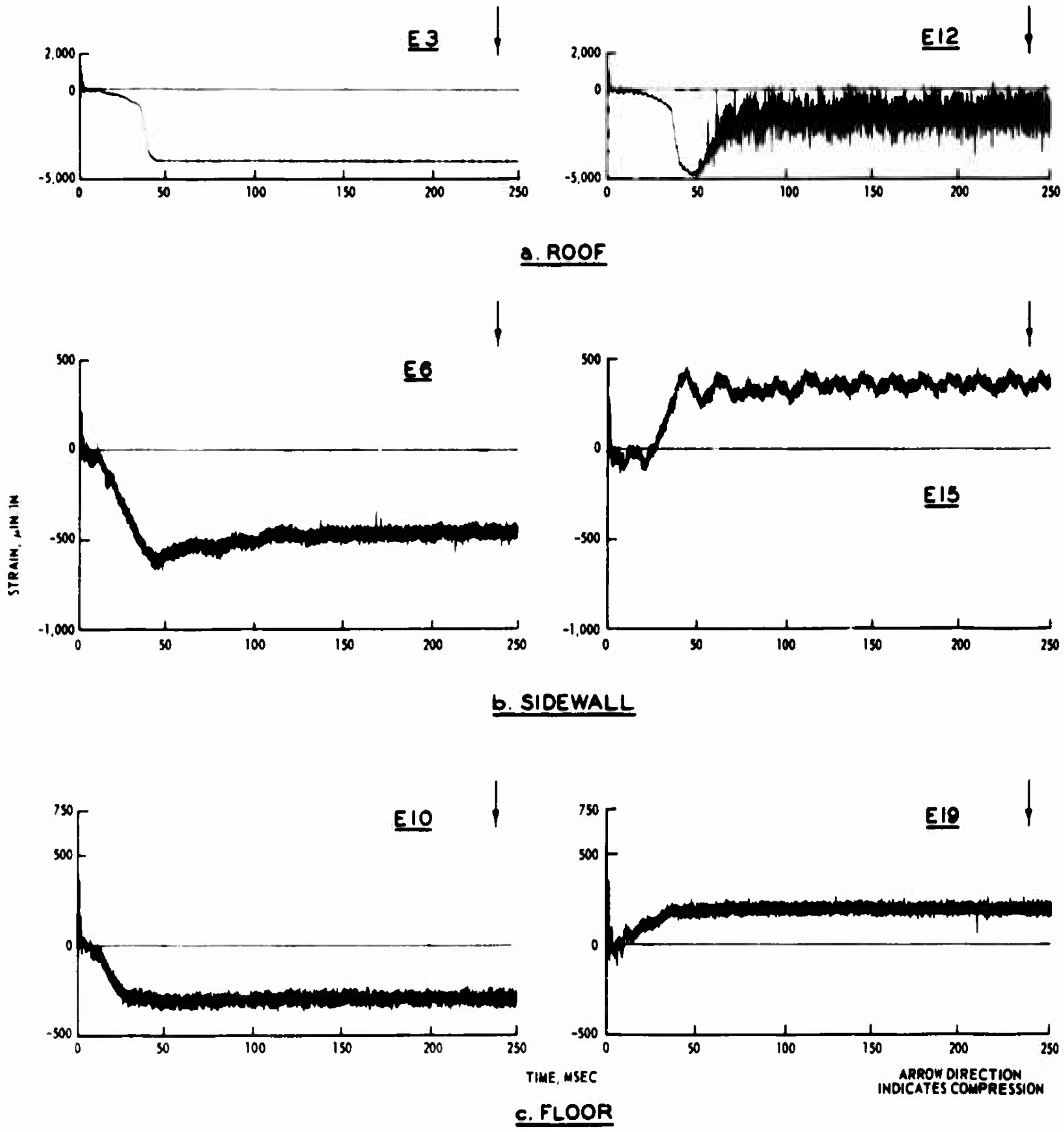


Figure 3.24 Selected strain gage signatures: Test 3.

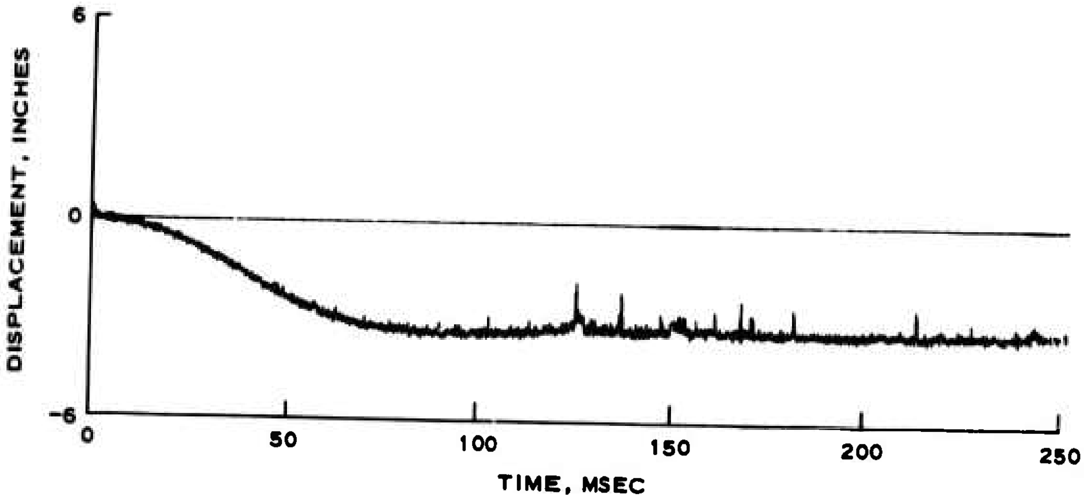


Figure 3.25 Relative displacement-time history between CONEX floor and roof; Gage CD1, Test 1.

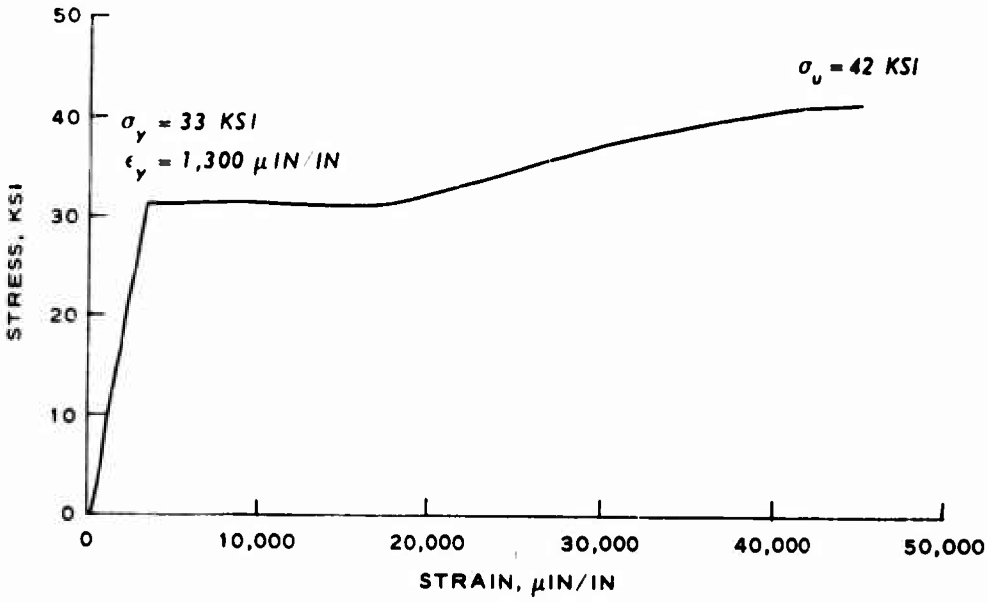


Figure 3.26 Stress-strain curve for CONEX tensile specimen.

CHAPTER 4

DISCUSSION OF RESULTS

4.1 STRUCTURAL INTEGRITY

Analysis of the strain data for Tests 1 and 3 as presented in Chapter 3 indicates that yielding occurred only at the structure roof. It was noted that yielding occurred on both the plate and corrugated roof sections in Test 1, whereas only the corrugated roof section yielded in Test 3. For both tests, the strains recorded on the floor and sidewall were considerably less than the ultimate yield strain. Since Test 2 was a repeat shot on the Test 1 structure, which had incurred permanent deformation, the results were not considered representative of the ultimate load-carrying capacity of the CONEX. However, it is believed that the Test 2 results are representative of the most probable failure mode of the CONEX; consequently, the test data were included in this report but were not considered in the final analysis.

A stiffness relation was developed to compare roof displacements resulting from Tests 1 and 3. The stiffness relation is defined as:

$$K_i = \frac{P_m}{\Delta_{max}}$$

where

K_i = stiffness for the i^{th} test

P_m = mean pressure, psi

$$\Delta_{max} = \begin{cases} \text{maximum dynamic peak midpoint displacement of the roof for dynamic } K_i \text{, inches} \\ \text{permanent midpoint displacement of the roof for static } K_i \text{, inches} \end{cases}$$

Using the permanent displacement mean pressures shown in Table 3.1, the static stiffness can be determined as:

$$K_1 = \frac{11 \text{ psi}}{3.2 \text{ inches}} = 3.5 \text{ psi/in}$$

$$K_3 = \frac{15 \text{ psi}}{2.2 \text{ inches}} = 6.9 \text{ psi/in}$$

Then the ratio

$$\frac{K_3}{K_1} = 2.0$$

Hence, the inverted floor configuration (Test 3) yields a system that is twice as stiff as the ordinarily placed container (Test 1).

In order to determine the dynamic stiffness, the dynamic displacements shown in Table 3.1 can be used in lieu of the permanent displacements. Hence,

$$K_1 = 2.2 \text{ psi/in}$$

$$K_3 = 4.7 \text{ psi/in}$$

yielding a ratio of

$$\frac{K_3}{K_1} = 2.1$$

As in the static case, the inverted floor configuration is the stiffer of the two systems.

The stiffness calculations are based on the assumption that the floor displacements (Figure 3.18) are insignificant as compared with the roof midpoint displacements shown in Table 3.1.

4.2 IN-STRUCTURE ENVIRONMENT

In evaluating underground structures that are to be occupied by personnel, consideration must be given to the shock and acoustic environment.

Figure 4.1 was extracted from a paper (Reference 4) on the effects of overpressures on the human ear. Recorded peak internal pressure from Test 1 was less than 2 psi; consequently, the probability of ruptured eardrums of occupants appears to be approximately 0.1 percent. The peak internal pressure from Test 3 was considerably less than that measured in Test 1.

According to the information published in Reference 5 on the tolerance of humans to impacts, the magnitudes and durations of accelerations measured on the structure floor for Tests 1 and 3 are significantly below injury levels.

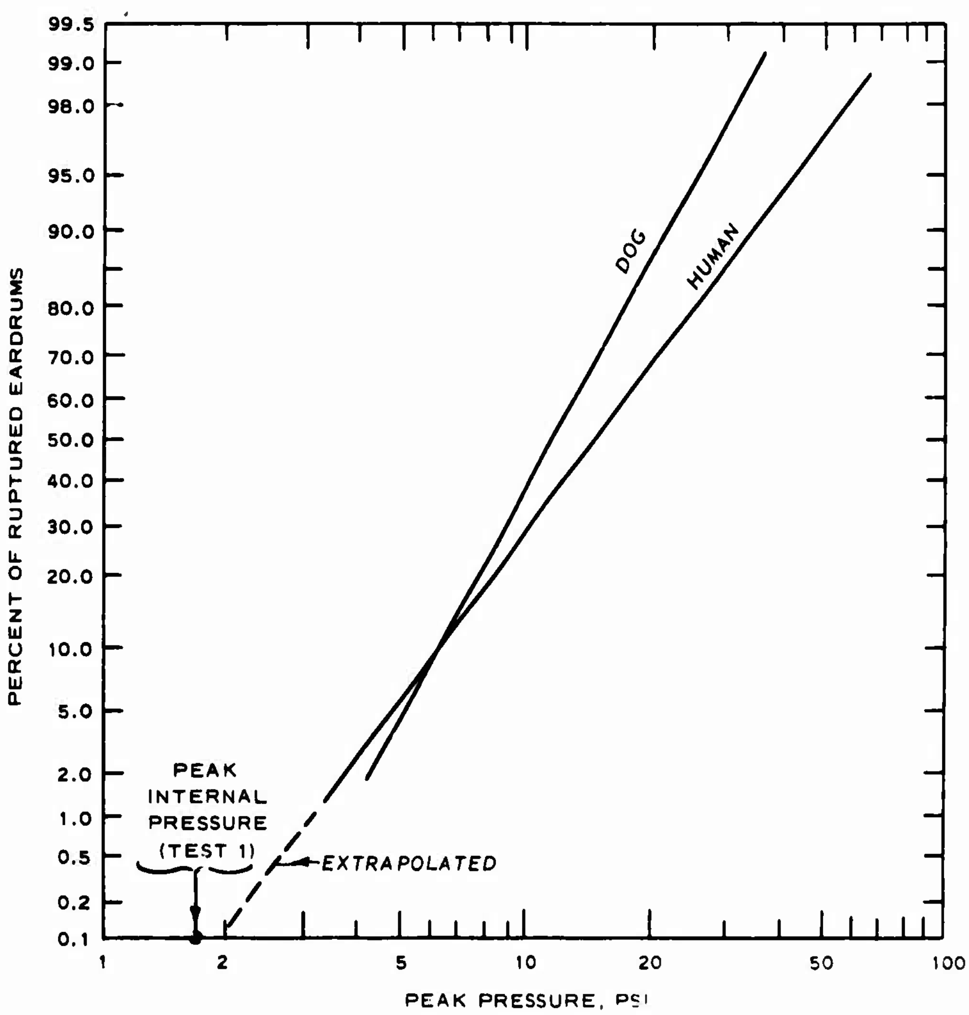


Figure 4.1 Tolerance of eardrums to fast-rising overpressures (from Reference 4).

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

Based on the results of this investigation, the following conclusions and recommendations were reached

1 If the CONEX is utilized as a small protective shelter, a definite structural advantage can be achieved by placing the structure upside down. This emplacement configuration would be desirable against conventional or nuclear weapon threats.

2. For peak pressures up to at least 15 psi resulting from the detonation of a nuclear device, occupants of the CONEX would not experience adverse shock or acoustical environments

3 Based on the observed strains from this test series, it is believed that an inverted CONEX would withstand overpressures in excess of 15 psi, however, additional testing would be necessary to establish the ultimate load-carrying capacity of the shelter.

4 These tests have shown that the CONEX is potentially an effective shelter against the blast effects of a nuclear device. Therefore, it is recommended that in future programs, consideration be given to bunk arrangements, entrances, exits, ventilation, emplacement techniques, and other pertinent design and environmental criteria.

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13. ABSTRACT

The objective of the test program reported herein was to determine if a large metal shipping container would provide a sufficient degree of protection from simulated nuclear weapon blast effects to make it suitable as a small protective shelter. This report describes the tests of two Container Express (CONEX) containers that were instrumented and subjected to blast loads in the Large Blast Load Generator (LBLG) facility at the U. S. Army Engineer Waterways Experiment Station. The containers were buried in dense, dry sand with 18 inches of sand over the roof and subjected to blast load pressures of approximately 11, 15, and 34 psi. A total of 45 channels of instrumentation were used to measure the following parameters: strain in the roof, sidewall, and floor; vertical deflection of the roof; accelerations in the roof, sidewall, floor, and free field; blast pressure at the soil surface and free field; and pressure inside the container. For the first two tests, a container was placed base down in the LBLG and subjected to pressures of 11 and 34 psi, respectively. The initial test caused only moderate damage to the container; however, complete roof collapse resulted from the second test. For the final test, an inverted (base up) container was subjected to a pressure of 15 psi. Damage to the container was moderate. Results of the test program indicate that the CONEX container could be utilized as a small protective shelter. If the container were buried with the base up, it is believed that it would withstand a pressure load of approximately 20 psi.

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Blast effects						
Containers						
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